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PREPARING FOR THE INTERNET OF THINGS

KEEPING UP WITH TECH INNOVATIONS

HOW DOES OUTSOURCING FIT IN?

IMPORTANCE OF TEST & MEASUREMENT

SEARCH
PARTS

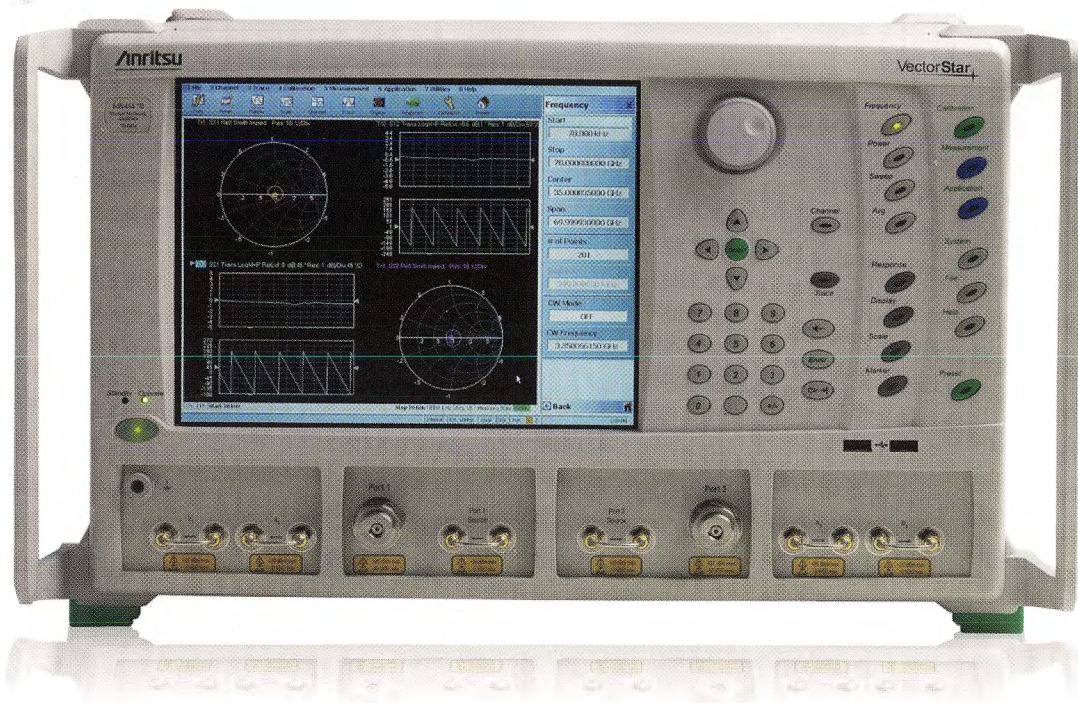
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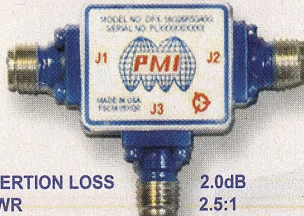
Threshold Detectors

USB Products

18GHz to 40GHz

DIPLEXER

PMI MODEL No: DPX-18G26R5G40G



- INSERTION LOSS 2.0dB
- VSWR 2.5:1
- K BAND PASSBAND 18GHz Min., 25GHz Max
- Ka BAND PASSBAND 28GHz Min., 40GHz Max
- K BAND REJECTION 32 to 46GHz, >60dBc
- Ka BAND REJECTION DC to 22GHz, >60dBc
- SIZE 0.80" X 0.60" X 0.38"

18GHz to 26.5GHz

HIGH PASS FILTER

PMI MODEL No: HPF18G-DC15G



- INSERTION LOSS 1.5dB
- PASSBAND 18 to 26.5GHz
- VSWR in PASSBAND 2.0:1
- REJECTION DC to 15GHz, >60dBc
- SIZE 0.64" X 0.58" X 0.38"

DC to 26.5GHz

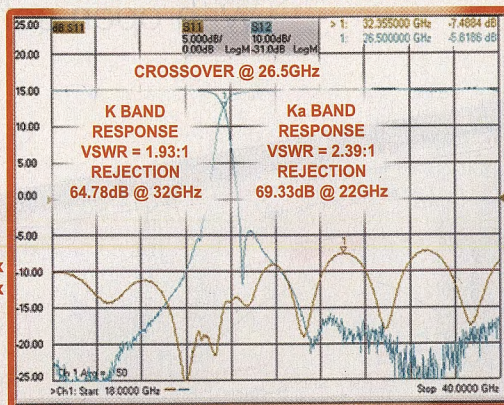
LOW PASS FILTER

PMI MODEL No: LPF26R5-28R5G40G

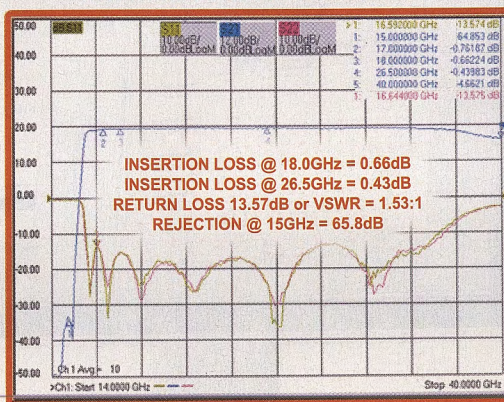


- INSERTION LOSS 1.5dB
- PASSBAND DC to 26.5GHz
- VSWR in PASSBAND 2.2:1
- RIPPLE +/-0.75dB Max
- REJECTION 28.5 to 40GHz, >25dBc
- SIZE 0.45" X 0.38" X 0.50"

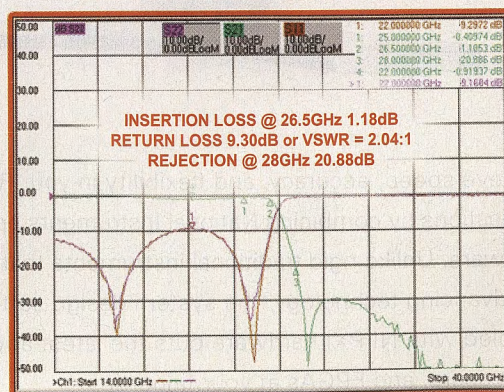
SWEPT DATA ON DPX-18G26R5G40G



SWEPT DATA ON HPF18G-DC15G



SWEPT DATA ON LPF26R5-28R5G40G



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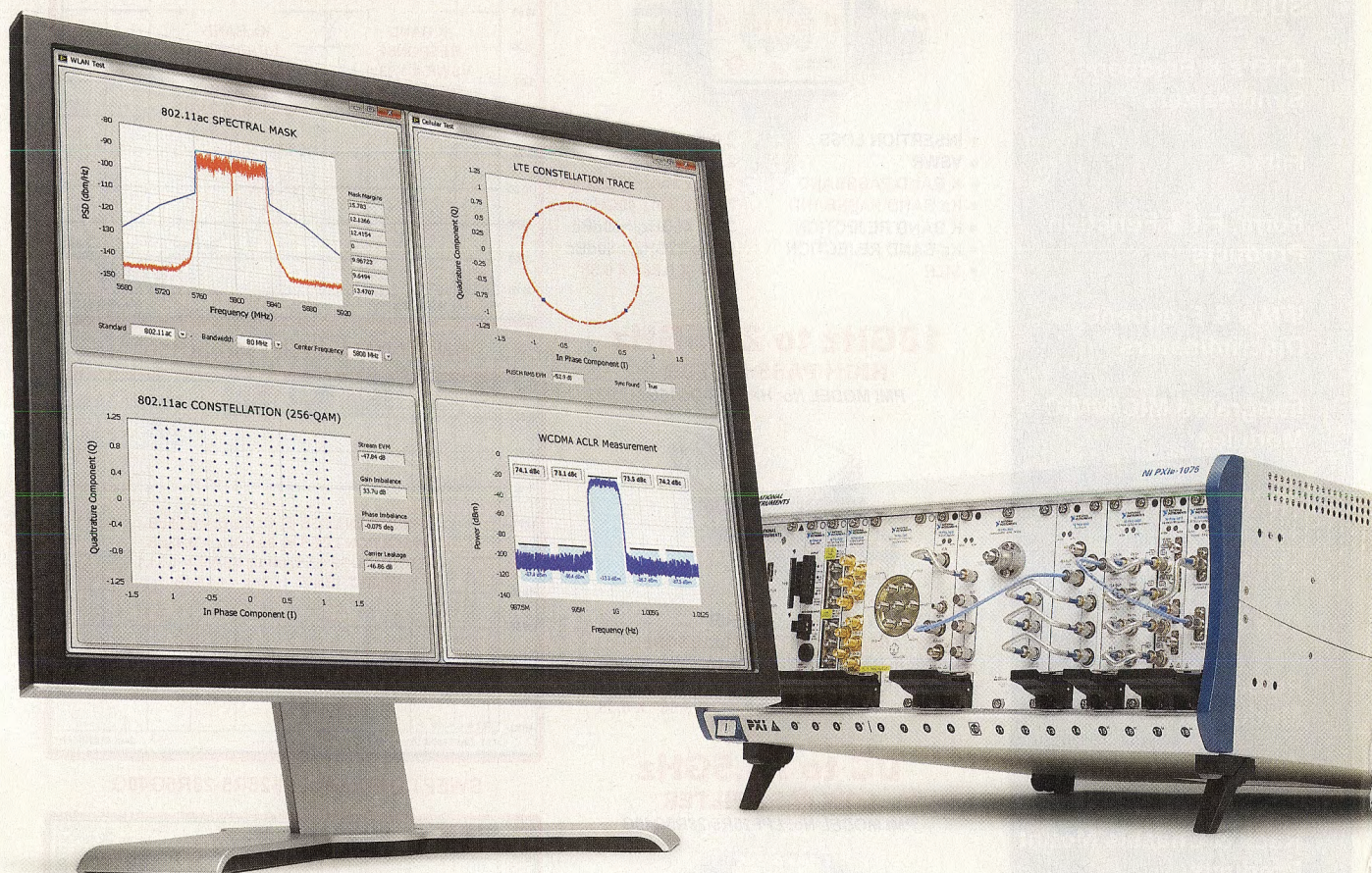
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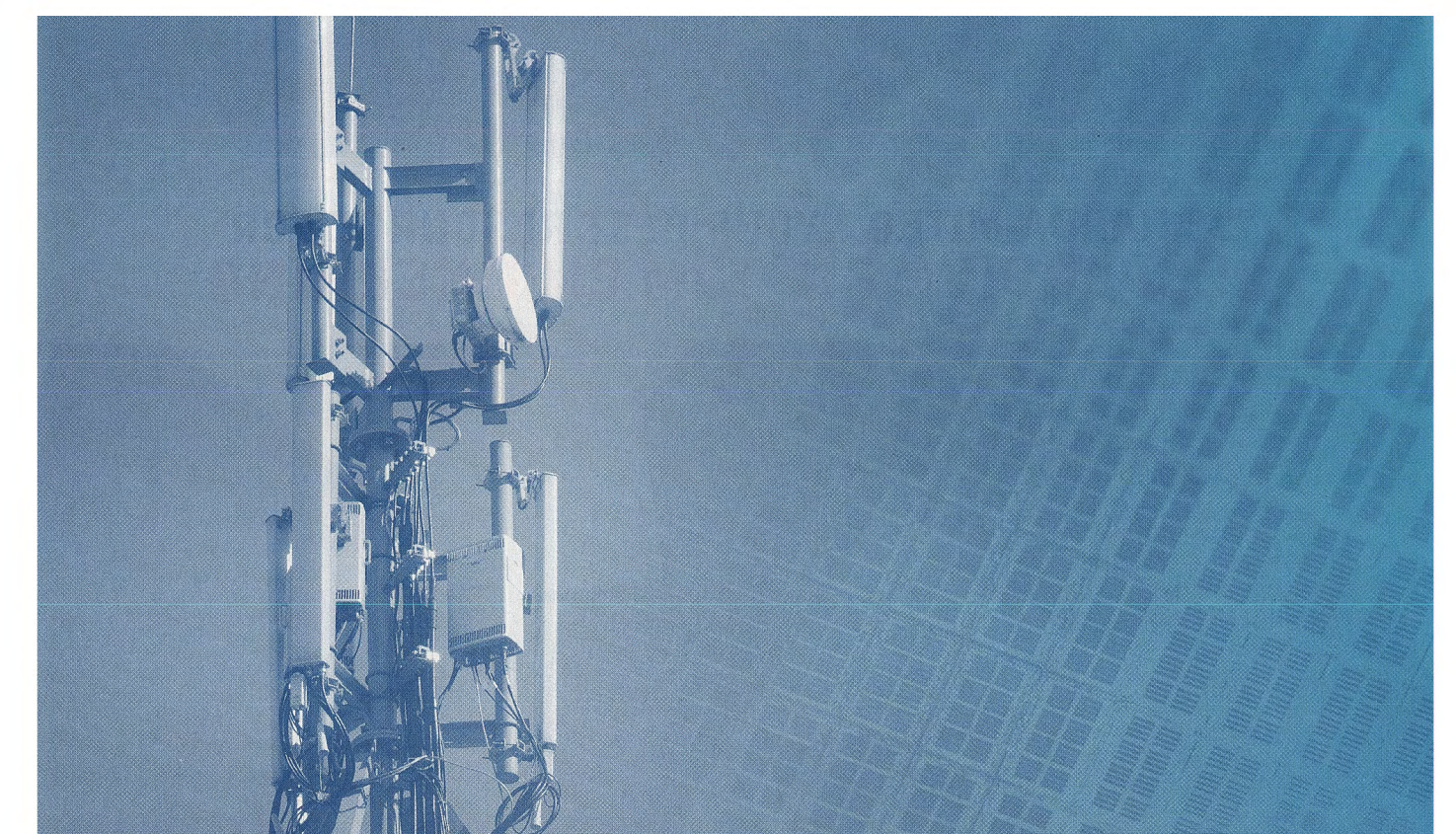
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In This Issue

FEATURES

34 COVER STORY:

MICROWAVES & RF'S 2015 SALARY SURVEY

While salaries remain stable, challenges such as new technologies and outsourcing are impacting overall job satisfaction.

62 NOVEL MICROSTRIP ANTENNA AIMS AT UWB APPLICATIONS

By enlisting a partially slotted ground plane and a step-cut approach to forming radiating elements, this compact microstrip antenna design achieves the wide impedance bandwidth needed for UWB systems.

68 WHAT'S THE STATE OF GaN POWER AMPLIFICATION?

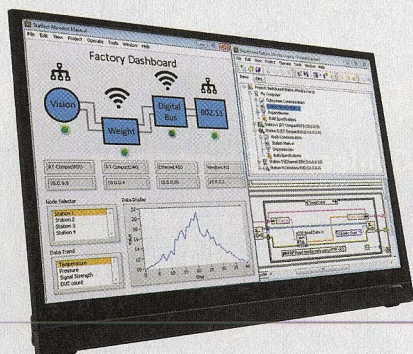
Improvements in GaN power semiconductor technology and modular design enable high-power CW and pulsed amplifiers at microwave frequencies.

73 ADJUSTING AMPLITUDE THROUGH ATTENUATION

Attenuators can control signal amplitudes in a variety of ways, even with attenuation that changes as a function of temperature.

77 WHAT'S THE DIFFERENCE BETWEEN ADCs AND DACs?

Data converters have many similarities, and both types are trending toward smaller packages, increased functionality, and lower operating power levels.



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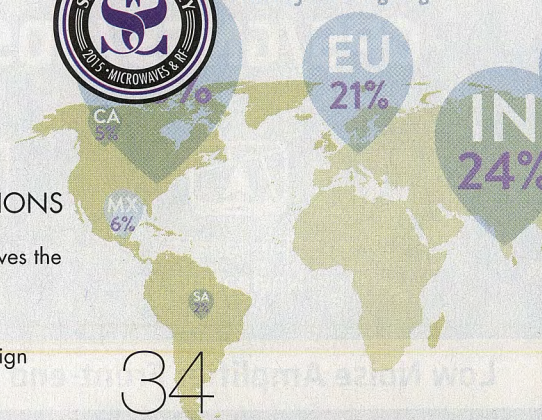
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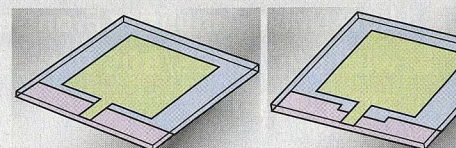
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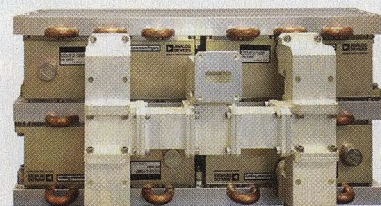
Where jobs are going



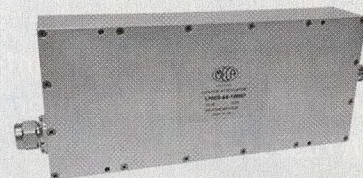
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68



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82





GPS/GNSS/BDS Radio Receiver Solutions



Personal
Navigation



Cellular



Tablet



Wearables

Low Noise Amplifier Front-end Modules (LNA FEMs) with Integrated Filters

Low Noise Amplifier Front-end Module with GPS/GNSS/BDS Pre- and Post-filters **SKY65903-11**

- Small signal gain: 14.2 dB
- In-band IIP3: -7.3 dBm
- Low noise figure: 1.7 dB
- Package: MCM 16-pin 2.5 x 2.5 mm

BDS/GPS/GNSS Low Noise Amplifier **SKY65605-21**

- Small signal gain: 19 dB typical
- High IIP3
- IP1 dB: up to -14.0 dBm
- Low noise figure: 0.75 dB typical
- Package: QFN 6-pin, 0.7 x 1.1 mm

Low Noise Amplifier Front-end Module with GPS/GNSS/BDS Pre-filter **SKY65715-81**

- Wideband pre-filter
- Small signal gain: 16.5 dB typical
- High, out-of-band IP2 and IP3
- Package: MCM 6-pin 1.7 x 2.3 mm

GPS/GLONASS/Galileo/BDS Low Noise Amplifier **SKY65611-11**

- Small signal gain: 17.2 dB typical
- Out of band IIP3: 0 dBm
- Low noise figure: 0.6 dB typical
- IP1 dB: up to -16.5 dBm
- Package: DFN 6-pin, 1.1 x 0.9 mm

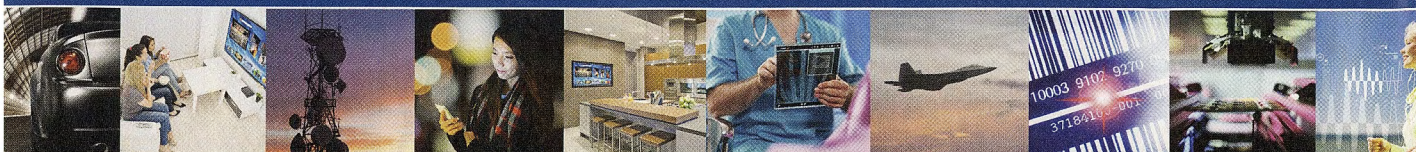
Low Noise Amplifier Front-end Module with GPS/GNSS Pre-filter **SKY65713-11**

- Small signal gain: 16.5 dB typical
- Low noise figure: 1.6 dB typical
- Excellent out-of-band rejection
- Package: MCM 8-pin 1.1 x 1.5 mm

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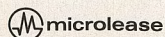
MIL-PRF-28800F Class 2 rugged

Agrees with benchtop measurements

CAT + VNA + spectrum analyzer



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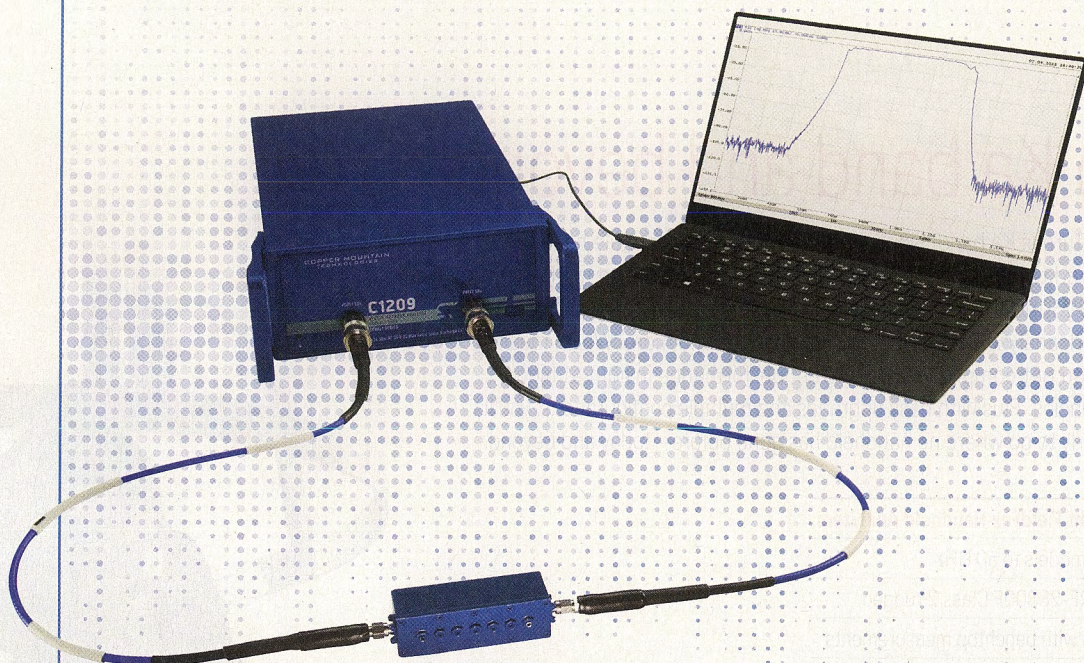
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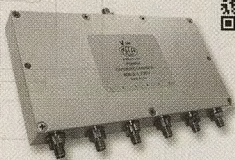
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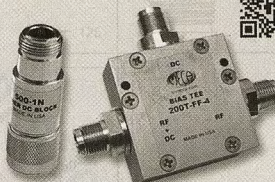
20 MHz - 40 GHz
SMA, 2.92, QMA, N,
TNC, BNC, RPTNC 4.1/9.5 & 7/16
Up to 120 watts

Attenuators



Up to 40 GHz
SMA, 2.92, QMA, N,
TNC, BNC, RPTNC & 7/16
Up to 150 watts

DC Blocks & Bias Tees



Up to 40 GHz
SMA, 2.92, QMA, N,
TNC, BNC, RPTNC & 7/16
Up to 7 amps

Low PIM Terminations



380 MHz - 2.7 GHz
10 watts - 250 watts
N, 4.1/9.5 & 7/16 DIN

Jumpers & Adapters



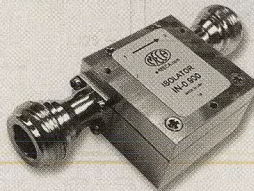
Up to 18 GHz
SMA, N, 4.1/9.5 & 7/16
RG, LMR & T-flex

Directional Couplers/Hybrids



0.4 - 40 GHz
SMA, 2.92, QMA, N,
TNC, BNC, RPTNC & 7/16
Up to 500 watts

Circulators/Isolators



Up to 40 GHz
SMA, 2.92, N, & 7/16
Up to 250 watts

Low PIM & D.A.S Equipment



Terminations, Attenuators,
Splitters, Adapters & Jumpers
N, 4.1/9.5 & 7/16

BETTER BUILDINGS / BETTER NETWORKS



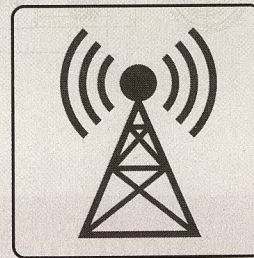
Public Safety



Satcom mmWave
Military



Aeronautical/Space
Transportation

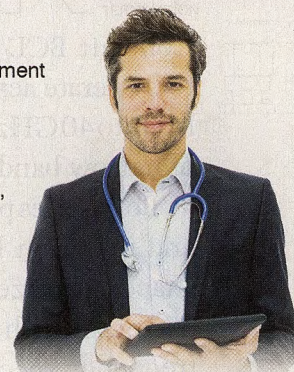


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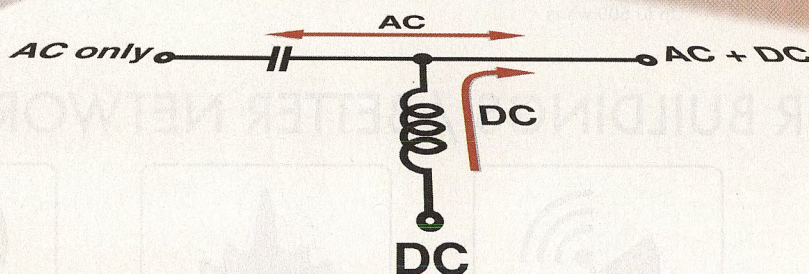
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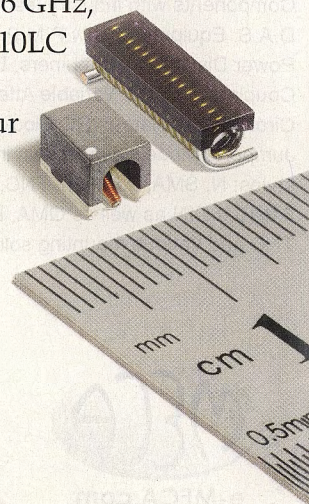
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TAKING THE MEASURE OF MICROWAVE POWER METERS

<http://mwrf.com/test-measurement-analyzers/taking-measure-microwave-power-meters>

Microwave power meters are among a collection of instruments, such as oscilloscopes and spectrum analyzers, that should be on every high-frequency designer's workbench. Over the last decade, the variety of available RF/microwave power meters has grown, to where these instruments are now available in many shapes and sizes, from rack-mount units to portable instruments and even meters that can be powered and controlled by a laptop computer using a USB connection.

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20 QUESTIONS

HOW MUCH DO YOU KNOW ABOUT MICROWAVES?

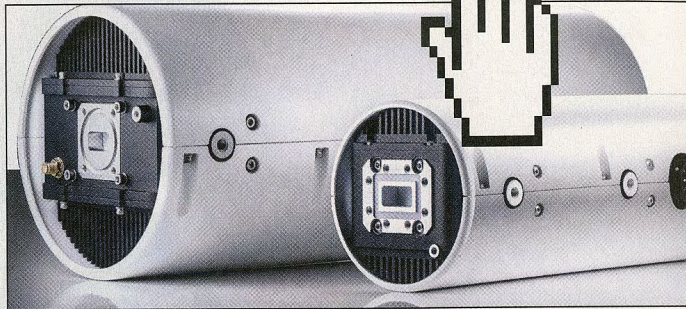
TAKE THE QUIZ >

WIRELESS QUIZ:

HOW MUCH DO YOU KNOW ABOUT MICROWAVES?

<http://mwrf.com/blog/wireless-quiz-how-much-do-you-know-about-microwaves>

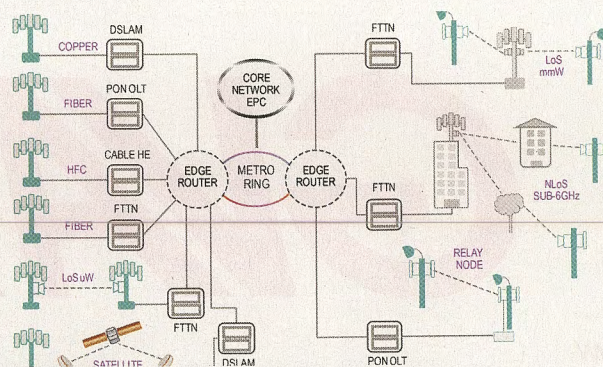
If you are an experienced RF/microwave engineer, this quiz will be trivial to you...or not. While it is basic theory and practice, aimed at the engineer just getting into RF, it may be an eye-opener for others, as well. And at the end of the quiz, make sure to download your free 2015 U.S. and European Frequency Allocation charts!



5 AREAS IMPACTING THE FUTURE OF SATCOM

<http://mwrf.com/passive-components/5-areas-impacting-future-satcom>

The latest RF/microwave technology is enhancing performance for the satellite-communications industry with a wide range of products. Today's satcom market can be analyzed by examining five focal points: Ka-band products, GaN devices, solid-state power amplifiers (SSPAs), traveling-wave-tube amplifiers (TWTAs), and passive components.



BACKHAUL ALTERNATIVES FOR HETNET SMALL CELLS

<http://mwrf.com/systems/backhaul-alternatives-hetnet-small-cells>

This two-part article series reviews mobile wireless backhaul systems deployed in 4G heterogeneous (HetNet) networks. Part 1 examines wireless backhaul market drivers, equipment trends, and the toolbox of different backhaul solutions deployed across cellular radio-access networks.

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US patent 6,943,629

*Low frequency cut-off determined by coupling cap.
For GVA-60+, GVA-62+, GVA-63+, and GVA-123+ low cut off at 10 MHz.
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NOTE: GVA-62+ may be used as a replacement for RFMD SBB-4089Z
GVA-63+ may be used as a replacement for RFMD SBB-5089Z
See model datasheets for details

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Editorial

NANCY K. FRIEDRICH
Content Director
nancy.friedrich@penton.com



How Do You Stack Up?

Welcome to this year's annual *Microwaves & RF* compensation survey, beginning on page 34. In surveying our audience across our family of brands, we found similar findings from *Electronic Design* to *Machine Design*, *Hydraulics & Pneumatics*, and *Global Purchasing*. Among the major trends were more focus and interest on the Internet of Things (IoT) and Industrial Internet of Things (IIoT)/Industry 4.0. Engineers are increasingly working on products and solutions for the IoT, while they and procurement professionals and management are also looking at how the IoT will impact the way they do their jobs.

Job satisfaction is currently very high. Engineers, for example, feel well compensated for their work and are generally happy with their career paths. They also feel optimistic about the state of the engineering industry, although some concerns remain about the economy, outsourcing, and IoT adoption. Among our Machine Design and Hydraulics & Pneumatics audiences, for example, there is some concern over manufacturing jobs being minimized or even phased out with IoT adoption.

For engineers, one of the biggest challenges remains staying up to date on the latest technologies. To accomplish this goal, our audience cites many online resources, ranging from white papers and e-books to webcasts and videos. They of course contend with time-to-market challenges and other job pressures, but by and large, they get a lot of satisfaction from overcoming those challenges. Interestingly, when they need to take a break and clear their heads, they most commonly shared that they go for a walk.

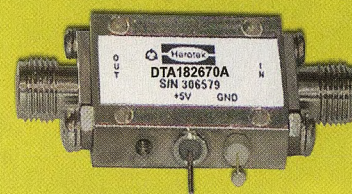
Across the industries we reach, more individuals are relying on smartphones to tie up business at the end of the day or prepare for what faces them in the morning. They also are paying more attention to social-media outlets like LinkedIn, Twitter, and Facebook. Some cite that they use Twitter (and Facebook, but to a lesser extent) to stay updated, while LinkedIn continues to reign as the career-networking resource.

What about the future? Across the board, we continue to see the majority of responses pointing to concern over the next generation. The consensus is that, despite today's efforts to bring more students into technology fields of study and careers, we're facing an engineering shortage. It follows that specialized areas, like the microwave and radio-frequency (RF) market, are facing an even bigger chasm as companies look to the next generation. Many of the people that laid the groundwork for today's technical breakthroughs have retired or are nearing retirement. While they brought in talent behind them, most do not think it is enough to bridge the gap.

Hopefully, all of today's technical-outreach efforts will increasingly produce interest from the next generation. In the meantime, don't forget to evangelize engineering and technology-related fields in your own circles. The majority of survey respondents said that they would recommend their professions, so why not start if you haven't already? And don't forget to take a deeper look at how people in your industry are compensated to see where you stand. **mw**

DETECTORS FOR VERY LOW SIGNALS

Direct Measurement of Microwave
Signals at -80 dBm or lower
over 1 to 40 GHz



MODEL	FREQ RANGE (GHz)	MIN VOLTAGE SENSITIVITY K (mV/μW)	TYP TSS (dBm)
DTA1-1860A	1-18	10	-60
DTA1-1870A		100	-70
DTA1-1880A		1000	-80
DTA182660A	18-26	10	-60
DTA182670A		100	-70
DTA182680A		1000	-80
DTA264060A	26-40	10	-60
DTA264070A		100	-70
DTA264080A		1000	-80
DTA184060A	18-40	10	-60
DTA184070A		100	-70
DTA184080A		1000	-80

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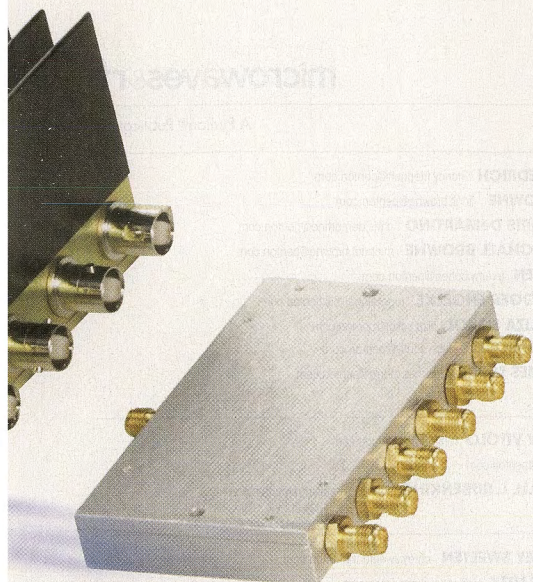
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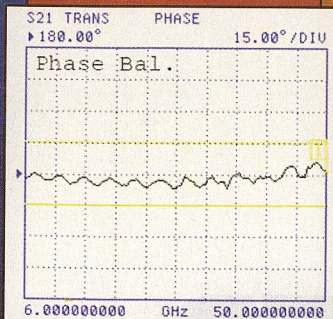
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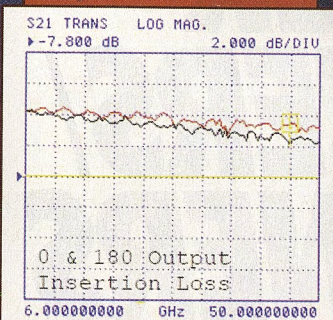
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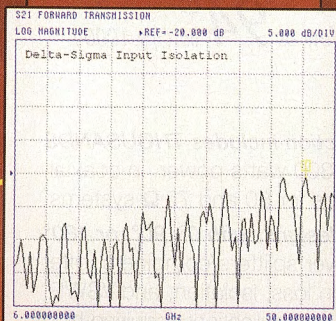
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OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

CA01-2111	0.4-0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8-1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2-1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2-2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7-2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7-4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4-5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25-7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0-10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75-15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35-1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1-3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9-6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0-12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0-12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2-13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0-15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0-22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0-4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0-6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0-12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0-18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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TRADEOFFS WHEN CHISELING CIRCUITS

I have enjoyed reading *Microwaves & RF* magazine for many years, and especially your special reports on specific topics. One example of this is "Weighing the Options for RF/MW Circuit Materials," which appeared in the August 2015 issue. As many of your readers are aware, printed-circuit-board (PCB) materials are the foundations for many RF and microwave circuits. As your editor pointed out in that article, the choice of PCB materials can potentially provide excellent long-term performance.

The article provided helpful information on such PCB material requirements as thermal conductivity and how different

types of commercial circuit materials react to different application operating conditions. I believe that the article explained how the choice of high-performance dielectric circuit materials (typically using consumer materials, such as those supplied by Rogers Corp.), could help achieve target performance levels at microwave through millimeter-wave frequencies.

The article also provided sections on the use of low-cost PCB materials, like FR-4, and how these materials would compare to the performance levels of different active and passive RF and microwave circuits fabricated on circuit materials. The FR-4 materials feature lower relative dielectric constant (ϵ_r) values than the

previously mentioned circuit materials, which would also be at considerably higher prices than the FR-4 materials.

Although the article appeared solid in its presentation of PCB details, it unfortunately also appeared somewhat one-sided in its presentation of high-end material information, focusing on Rogers Corp. but providing no information on circuit materials from other suppliers. In fairness to your readers, I would hope to see a follow-up article on high-frequency circuit materials from different suppliers.

IMMANUEL FAUSBINDER

EDITOR'S NOTE

Admittedly, the August article on circuit materials did focus heavily on Rogers Corp.'s

high-speed, high-frequency circuit materials. But yes, there are many additional excellent options on the market for high-frequency analog and high-speed digital circuit materials. As microwave circuit designers know, the relative dielectric constant and other circuit materials translate into the final size and performance of a particular circuit design, plus knowing what is available on the current market. Many companies, such as Arlon (www.arlon.med.com), Polyflon (www.polyflon.com), and Taconic (www.taconic-add.com), offer excellent selections of high-frequency, high-speed circuit materials, and also provide excellent design guidance and advice for the best use of their materials.

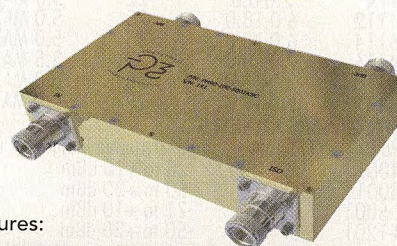
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	1000	0.5	1.5	20	0.25	1.15	PH90-88-108-1KN
100-500	500	0.8	3	18	0.3	1.3	PH90-100-500-R5N
	1000	0.8	2	20	0.3	1.25	PH90-100-500-1KN
200-400	500	0.5	2	23	0.2	1.2	PH90-200-400-R5N
	1000	0.5	2	20	0.2	1.2	PH90-200-400-1KN
250-1000	250	0.6	2	20	0.4	1.2	PH90-250-1000-R25S
	500	0.6	2	20	0.4	1.2	PH90-250-1000-R5N
400-1000	500	0.6	2	20	0.25	1.25	PH90-400-1000-R5N
	1000	0.6	2	15	0.2	1.2	PH90-400-1000-1KN
800-1600	250	0.4	2	23	0.25	1.2	PH90-800-1600-R25S
	500	0.5	2	20	0.2	1.25	PH90-800-1600-R5N
800-2500	250	0.6	4	20	0.4	1.25	PH90-800-2500-R25S
	200	0.5	4	18	0.3	1.25	PH90-800-4000-R2S
1000-2000	250	0.5	3	20	0.25	1.2	PH90-1000-2000-R25S
	500	0.5	3	20	0.25	1.22	PH90-1000-2000-R5N
2000-4000	500	0.55	6	18	0.2	1.25	PH90-2000-4000-R5N
	1600	0.55	6	18	0.2	1.25	PH90-2000-4000-1R5SC



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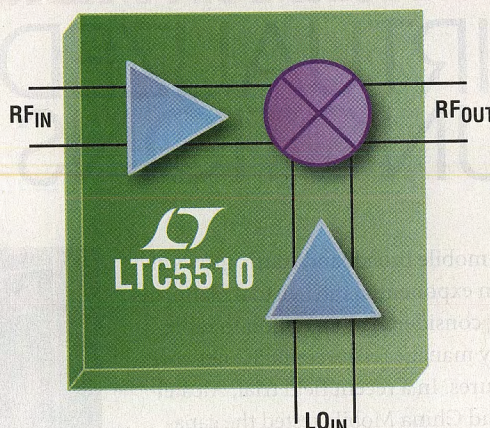
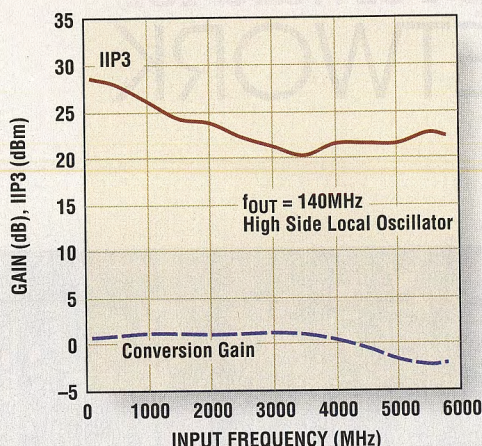
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News

Live Field Test Marks Step Forward for VIRTUALIZED NETWORK FUNCTIONS

As mobile broadband traffic grows at an exponential rate, virtual platforms are being considered as an option to more efficiently manage resources in 5G network architectures. In a recent field trial, Alcatel-Lucent and China Mobile tested the capabilities of a virtualized radio access network (vRAN) based on network function virtualization (NFV). The trial, which the companies have called the first “live” test of an NFV-based RAN, was conducted on the campus of Tsinghua University in Beijing.

The vRAN field trial was completed over an area of 4.42 sq. km. on the Tsinghua University campus, with the network providing coverage both indoors and outdoors to the approximately 31,000 undergraduate and graduate students. The network also exhibited dynamic load balancing based on the changing demands for access from users.

The vRAN technology, which is based on the concept of Cloud-RAN (C-RAN) architectures, successfully linked several distributed radio access points to a central programmable platform, with virtualization being used to carry out network processing functions. The network control functions were shifted to software platforms or virtual machines (VMs). These included enhanced scheduling and coordination and virtualized self-organizing-network (SON) functions to improve cell coordination and interference management.

While it was used on a relatively small scale in the trial, the vRAN concept is often considered a core network architecture. vRAN connects a large number of distributed radio receivers to a centralized baseband-unit (BBU) pool, providing high-bandwidth and low-latency communications. The network shifts certain BBU processing functions away from the radio receivers and into cloud-based data servers. Some previ-



ously centralized functions also are handled by remote access points, as the majority of processing functions are located around the edge of the network.

vRAN is also designed to navigate a heterogeneous-network (HetNet) infrastructure populated by small cells, macrocell base stations, and large-scale multiple-input multiple-output (MIMO) systems. vRAN technology combines these heterogeneous resources into a common resource, which can be distributed based on the processing loads at each cell, according to Alcatel-Lucent. The company notes that this is crucial for developing networks that support multiple access technologies, such as Wi-Fi, LTE, and LTE-Advanced.

Last year, Alcatel-Lucent deployed a virtual radio network controller (vRNC) in Mobily Saudi Arabia networks. It has been in active commercial service for more than a year. The company has signed research agreements not only with China Mobile but also with Telefónica, which has involved testing a virtualized service router (VSR) and other NFV technologies in its reference lab. ■

GaN PRODUCTION PROCESS SHIFTS to 6-Inch Wafers As Market Grows

ALTHOUGH GALLIUM NITRIDE

(GaN) power amplifiers support a wide range of frequency bandwidths and high breakdown voltages, the manufacturing process remains too costly to exploit these benefits on a large scale, due to the limited capacity of GaN production lines. In an attempt to increase its GaN capabilities, Qorvo recently scaled its QGaN25 production process to support monolithic microwave integrated circuits (MMICs) on 6-inch wafers, up from its previous 4-inch substrates.

For Qorvo, the transition is expected to more than double its existing GaN-on-silicon carbide (SiC) manufacturing capabilities, the company said in a recent statement. The 6-inch GaN wafers have more than twice the usable surface area than previous 4-inch wafers, resulting in a larger yield of integrated circuits (ICs) per

substrate. This process will also reduce the production cost of its GaN-based technologies, which are used in commercial base receiver stations (BTSSs), point-to-point radios, and military radars.

The production process was engineered as GaN technologies are growing more widespread. The market for GaN radio frequency (RF) devices is expected to reach about \$560 million in 2019, according to a recent Strategy Analytics report. This can be largely attributed to its steady presence in military-grade radars and increased usage in wireless infrastructure, the report noted. On the other hand, the shift toward small-cell architectures is expected to moderate future growth in the commercial sector, the report concluded.

Qorvo has stated that the latest GaN process is part of a strategy to convert all its GaN-

on-SiC production to 6-inch wafers, with gate lengths ranging from 0.15 μm to 0.50 μm . This production process can produce 12-watt X-band MMIC power amplifiers that reach 80% dc and RF yields. Full-rate production of the GaN wafers is anticipated for 2016, according to the company.

Qorvo has previous experience with 6-inch GaN wafers, but it has never produced the wafers on its QGaN25 production process. Before RF Micro Devices (RFMD) and Triquint Semiconductors merged to form Qorvo earlier this year, RFMD had produced 6-inch wafers using an existing gallium-arsenide (GaAs) foundry in 2013. At that point, the new process was part of the company's restructuring plan to convert all of its existing GaAs foundries into GaN production. ■

Photo courtesy of Thinkstock

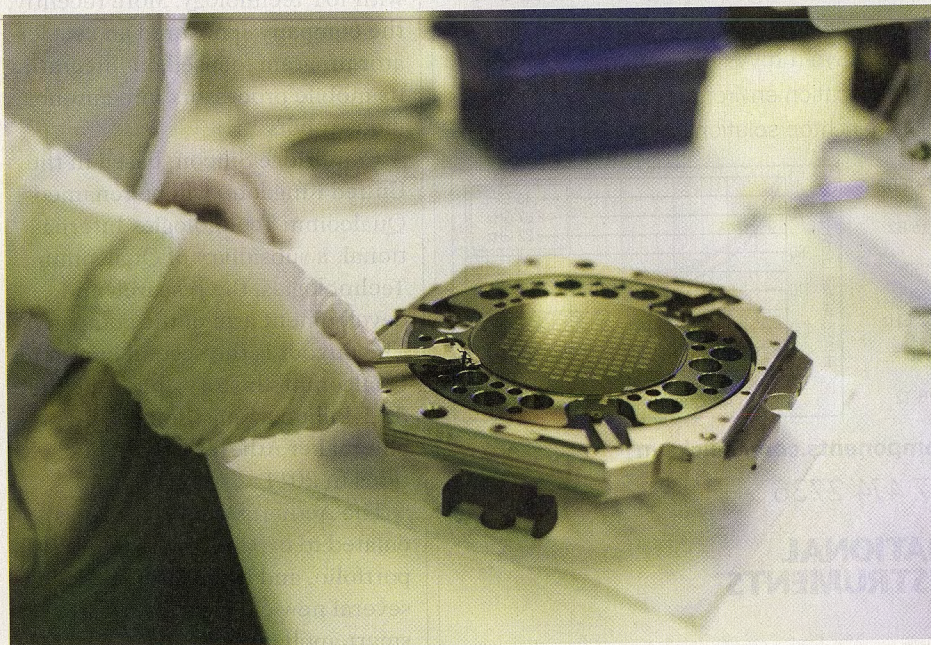


QUALCOMM BRACES for Internet of Things with Cambridge Silicon Buyout

QUALCOMM INC. is gearing up for the rapidly approaching Internet of Things (IoT) era. The San Diego-based company has completed its acquisition of Cambridge Silicon Radio Ltd. (CSR), a fabless semiconductor company specializing in wireless networking, for approximately \$2.4 billion. The transaction, which represents the second largest buyout in the company's history, was leveled at strengthening Qualcomm's position within the growing IoT markets.

As part of the transaction, Qualcomm acquired a wide range of system-on-a-chip (SoC) and software products used in mobile phones, personal navigation, connected vehicles, wearables, and other IoT platforms. These include Bluetooth technology, ARM processors, audio codecs, GPS, and MIPS-based imaging devices.

The additions not only complement Qualcomm's existing product lines but



also deepen its footprint in the IoT market, without having to design new chipsets from scratch—a high priority for semiconductor companies in recent years.

The semiconductor industry has witnessed a flood of mergers and acquisitions over the last

year. Many large semiconductor companies are buying out competitors that specialize in analog and mixed-signal chipsets, especially as the cost of design and manufacturing continues to increase. Intel Corp., for instance, purchased IoT-chipmaker and networking special-

ist Lantiq several months ago—a shift into the IoT market that was underlined in June, when Intel announced that it had purchased Altera Corp. for \$16.7 billion.

In March, NXP Semiconductor and Freescale signed an almost \$40 billion merger agreement to improve their position in a more connected, “smarter world,” as both companies termed it.

According to a recent report from Reuters, other analog and mixed-signal chipmakers, such as Linear Technology Corp. and Maxim Integrated, could be potential targets for large companies going forward.

The acquisition was announced toward the end of last year, as Qualcomm began to more actively expand its line of ARM processors into adjacent markets, including consumer robotics and data networking. Around the same time last year, the company also announced that it was developing a data server variation of its Snapdragon processor—a program intended to exploit the large amount of data traffic expected with IoT technology. More recently, the company sponsored an accelerator program focused on integrating its mobile processors into autonomous robots.

Cambridge Silicon, based in the United Kingdom, will be renamed Qualcomm Technologies International, a subsidiary of Qualcomm Technologies, the research and development arm of the company. The buyout is the second largest in Qualcomm's history, following the \$3.1-billion acquisition of Wi-Fi chipmaker Atheros Communications in 2011.

The Atheros deal was also calculated to expand Qualcomm's IoT portfolio, and it recently yielded several new chipsets for use in smart appliances. ■

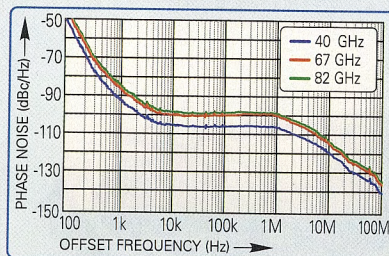
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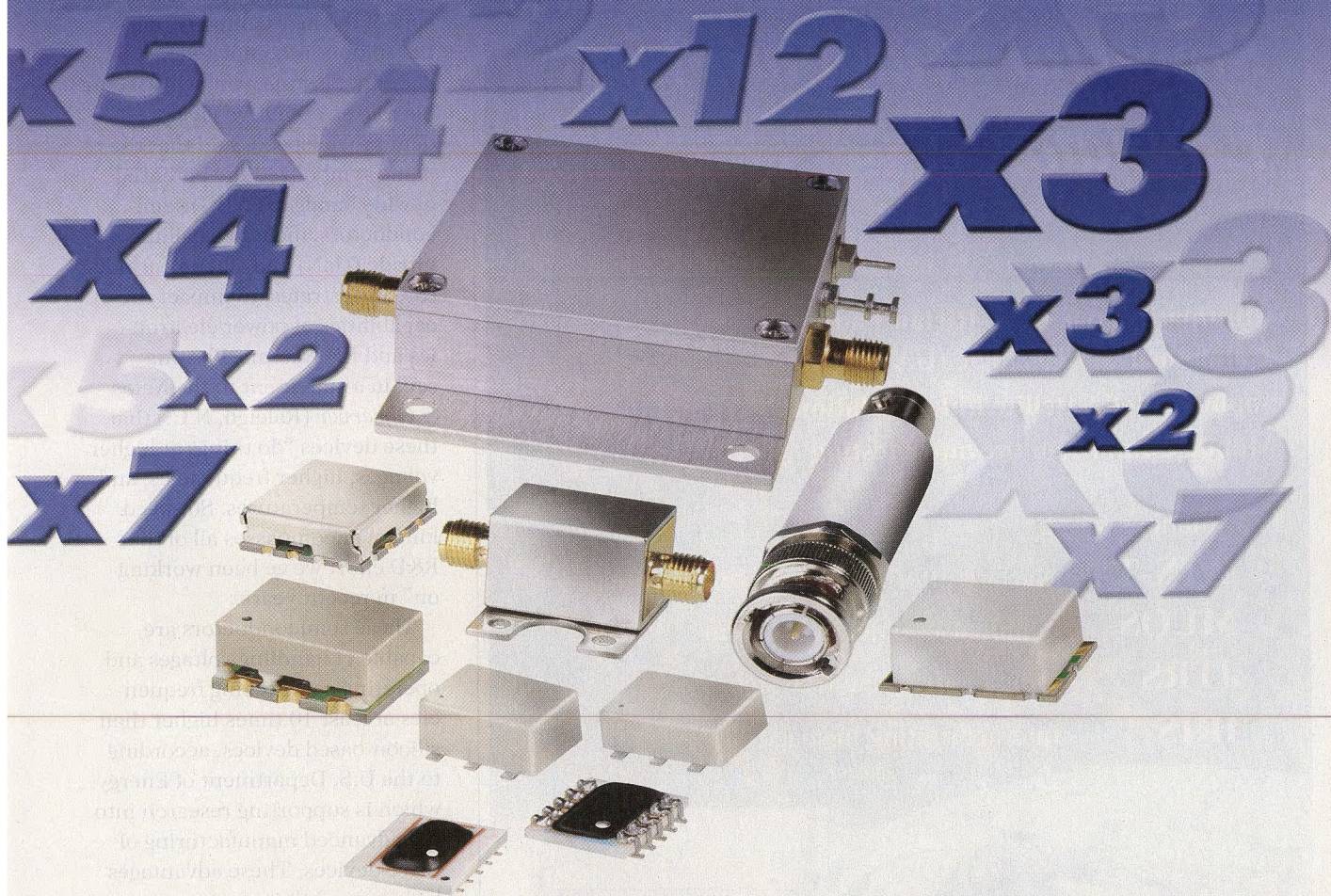
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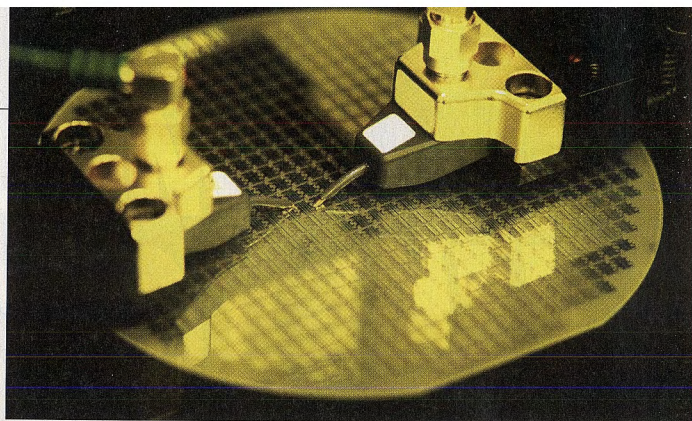
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CREE RENAMES POWER and RF Division, Emphasizing Wide Bandgap Devices

FOLLOWING UP ON its announced plan to spin out its Power and Radio Frequency (RF) division into a separate company, Cree Inc. recently unveiled that the division will be renamed Wolfspeed. Cree will retain majority owner-



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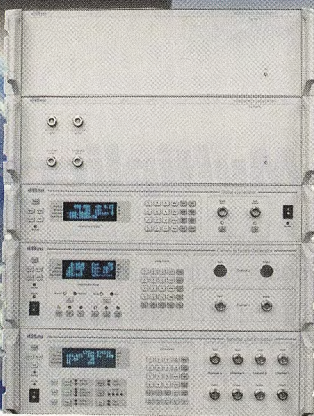
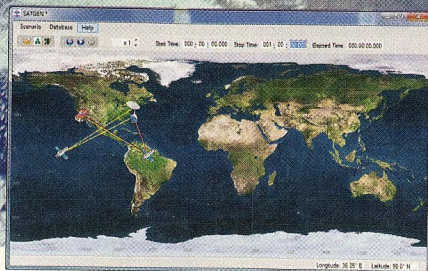
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ship of the new company once the spinout is completed.

Frank Plastina, who will assume his role as executive vice president at Wolfspeed, said that the name symbolized the potential of wide bandgap (WBG) semiconductors, including gallium nitride (GaN) and silicon carbide (SiC) substrates, to impact the capabilities of power electronics and RF systems. Plastina said in a statement to the *News & Observer* (Raleigh, N.C.) that these devices "do things at higher voltages, higher frequencies, and higher temperatures. So speed kind of encompasses all of that R&D effort we've been working on" in recent years.

These semiconductors are capable of handling voltages and operating at switching frequencies at least 10 times higher than silicon-based devices, according to the U.S. Department of Energy, which is supporting research into the advanced manufacturing of these devices. These advantages have caused them to grow more widespread in RF systems, especially in military-grade radars and wireless infrastructure. The market for GaN RF devices is expected to reach around \$560 million in 2019, according to a recent Strategy Analytics report.

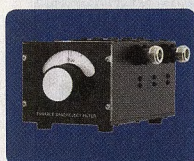
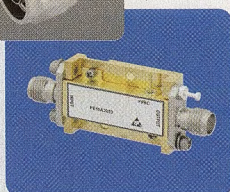
Wolfspeed operates a semiconductor foundry where it fabricates GaN-on-SiC substrates to be used in satellite, telecommunications, and radar systems. The foundry supports GaN production pro-

RF Solutions From RF Engineers

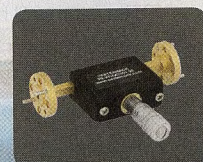
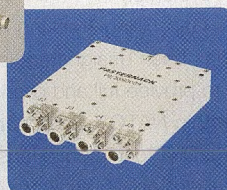
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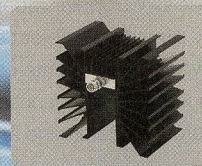
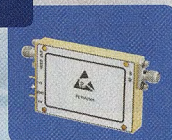
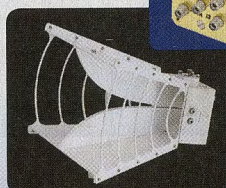
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cesses that generate high-electron-mobility transistors (HEMTs) on massive microwave integrated circuits (MMICs). The first production process creates a 0.4- μm gate-length HEMT that can be operated at drain bias of 28 to 50 V. The second process results in a 0.25- μm gate-length HEMT that can be operated at 28 to 40 V.

The new company structure is calculated to remove the strain from Cree's main light-emitting diode (LED) business, according to reports from earlier this year. Cree's LED business has taken a 37% fall in profits from last year, according to filings with the Securities and

Exchange Commission (SEC). The Cree Power and RF division, on the other hand, earned almost \$120 million in revenues last year—an almost 15% increase from revenues earned last year.

Wolfspeed will remain at its current location in Research Triangle Park in North Carolina near Cree's main headquarters in Durham. Arkansas Power Electronics International (APEI), which the company acquired in July to pursue a more diverse range of applications for its silicon-carbide (SiC) components, will continue operating under the Wolfspeed brand. ■

CW DOPPLER RADARS to Fill Gaps in Missile Defense Network

CONTINUOUS WAVE (CW) Doppler radars have the advantage of being immune to interference from large stationary objects and slow-moving debris. Coupled with simple, compact designs, these radars can be deployed over wide areas around uneven terrain or urban environments. For that reason, Lockheed Martin has entered into an agreement with Weibel Scientific, a Danish corporation specializing in this technology, to design CW Doppler radars that can fill gaps in ballistic missile defense (BMD) systems.

The Gap-Filling Tracking Radar (GFTR), as it has been designated, is being developed to provide full and overlapping coverage within NATO's European BMD architecture. Due to its continuous transmission and reception of ultrasound waves, the GFTR system will be capable of measuring the velocity and position of ballistic missiles in real-time. While CW Doppler radar systems usually only provide an object's velocity, Weibel has worked to integrate its radars with multiple receivers and advanced signal processing in order to determine an object's location.

The GFTR system is still being developed, but it will likely integrate technology that has been deployed in Weibel's other radars. These include multi-frequency operation to extend the range of its targeting capabilities. The multi-frequency surveillance and tracking radar (MFSR-2100), for instance, employs phased-array antennas, beam-shaping transmitters, and multi-beam receivers to target moving objects



at distances further than 1,000 km. The monopulse Doppler tracking radar system, on the other hand, is equipped with micro-strip array antennas and solid-state components.

Weibel Scientific has a history with United States military contracts. In 2012, as the U.S. military was investigating the potential of CW Doppler radars for missile defense, the company was awarded a \$36-million contract for the delivery of 1,995 Doppler radars.

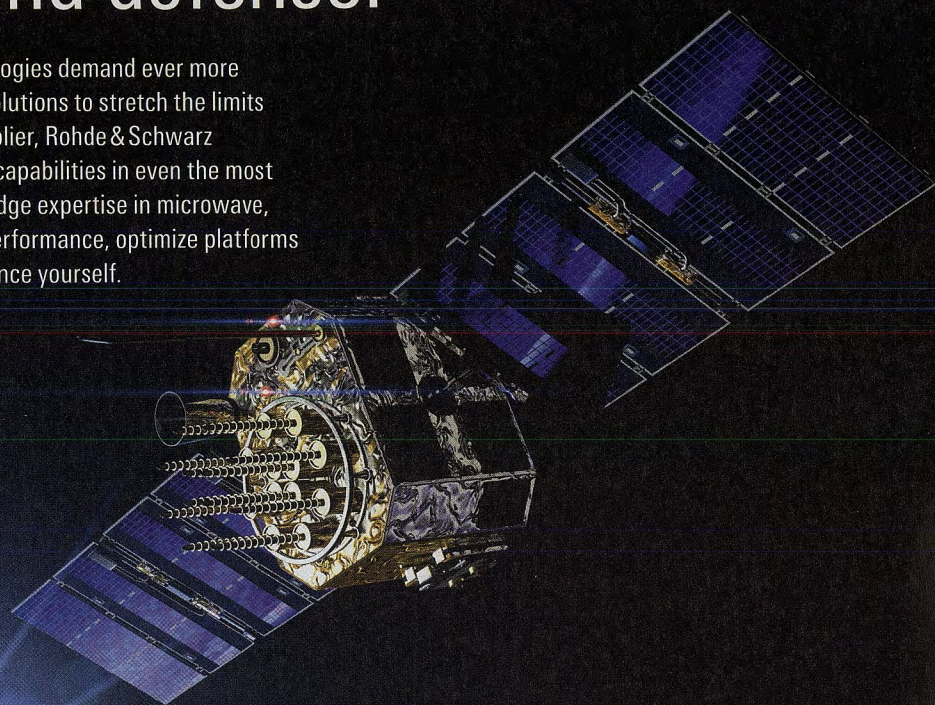
Weibel's multi-frequency tracking radar systems have also been used by NASA to track debris during rocket launches.

The agreement between Lockheed Martin and Weibel Scientific was signed after being approved by the Danish Business Authority. The GFTR system will be designed, developed, and tested at Weibel's facilities in Denmark and Lockheed Martin's BMD development site in Moorestown, N.J. ■

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Inside TRACK

with
Suresh Singamsetty,

Founder and CEO, WiSilica

Interview by CHRIS DeMARTINO

CD: Some of our audience may not be that familiar with the Internet of Things (IoT). Can you provide a brief description of it?

SS: Internet of Things (IoT) is a concept where any object/thing that can be controlled (lamps, switches, thermostats, fans, coffee makers, machines, vehicles, TVs, speakers, etc.), or sensed (temperature, humidity, light, motion, pressure, movement, steps, etc.) is connected to the Internet. Information from sensors is used to control objects and/or identify and predict potential connection issues.

CD: How much impact do you think the IoT will have on people's everyday lives?

SS: IoT will have a massive impact in all areas—from consumers to enterprises. It improves everyday lives around the clock—from gentle wake-ups by wearables, to providing you with a consistent and comfortable environment for best performance by automatically setting the right light, temperature, and humidity at home and the office—wherever you may go throughout the day.

In essence, IoT will provide an environment where people can really focus on their creativities and passions.

CD: With IoT on the horizon, what are the benefits of instituting an end-to-end IoT platform?

SS: An end-to-end IoT platform provides secured connectivity from device to application to cloud. With an open API, customers can develop new applications and/or integrate innovative, connected devices to their existing cloud or infrastructure with ease.



“IoT will have a massive impact in all areas—from consumers to enterprises. It improves everyday lives around the clock... In essence, IoT will provide an environment where people can really focus on their creativities and passions.”

CD: Can you provide a brief description of mesh networking technology?

SS: Mesh network is network topology where the participating devices will help each other deliver/distribute the data from one device to another even when they are not directly reachable. Key features in a robust network are Ad-Hoc, where devices form a network without any pre-configuration, and Self-Healing, where devices identify any breakdown in connectivity and reconfigure automatically.

Mesh networks use two techniques to relay messages: flooding, in which every device will relay all messages, with the drawback being network congestion; and routing, where only a few devices relay messages—more device resources are required for information.

CD: What are the benefits that Bluetooth low-energy (BLE) can offer to an IoT platform?

SS: The key benefit of BLE is smartphone support. Bluetooth low-energy devices communicate with smartphones, and use them as bridges to access the Internet—the reason wearables are completely dominated by BLE. BLE ICs are in the \$1 range—the lowest among any wireless technologies—due to the sheer volume of consumed Bluetooth ICs. This will help drive IoT adoption in low-cost devices. The power consumption of the BLE devices is low, and helps to provide long-life battery, powered-sensor devices. Basically, a smartphone ecosystem that is low-cost and low-power will enable BLE.

CD: What specific applications can employ such platforms?

SS: Versatile platforms enable a variety of applications including smart homes, energy management, smart lighting, retail solutions, proximity solutions, smart farming, asset tracking, and more.

CD: Do you believe there is one application that provides more benefits than others?

SS: The platform that blends multiple applications through connected devices will be the key for successful IoT deployment. The key applications that already greatly benefit users are power management, tracking, health monitoring and context/proximity-based content management. For example, our lighting solution provides the backbone mesh network—enabling sensors to save energy, tags to track assets, and health-monitoring devices to provide dynamic, real-time cohe-

“The key benefit of Bluetooth low-energy devices [is that they] communicate with smartphones, and use them as bridges to access the Internet.”

sive reports and alerts, and beacons to provide context/proximity-based content management. Safety and security are added natural benefits of such a platform.

CD: What impact do you think 5G will have on the IoT?

SS: IoT is about connecting everything all of the time, everywhere. 5G promises 1,000 times data rates, support for more network devices, and flexible data usage requirements with rapid adaption. This helps connect a number of IoT devices, which need a low data rate, and streaming devices that need high data rates in parallel. 5G can provide a unified framework, replacing different connectivity protocols.

CD: From WiSilica's standpoint, what should RFIC vendors do in order to prepare for IoT?

SS: From our standpoint, the connected-things entry cost needs to be very low for broader acceptance. RFIC vendors can play a key role in achieving this by providing integrated

SoCs with reasonable MIPS that are low-cost, low-power in active and inactive modes, contain built-in security engines, and integrate different sensors and controllers.

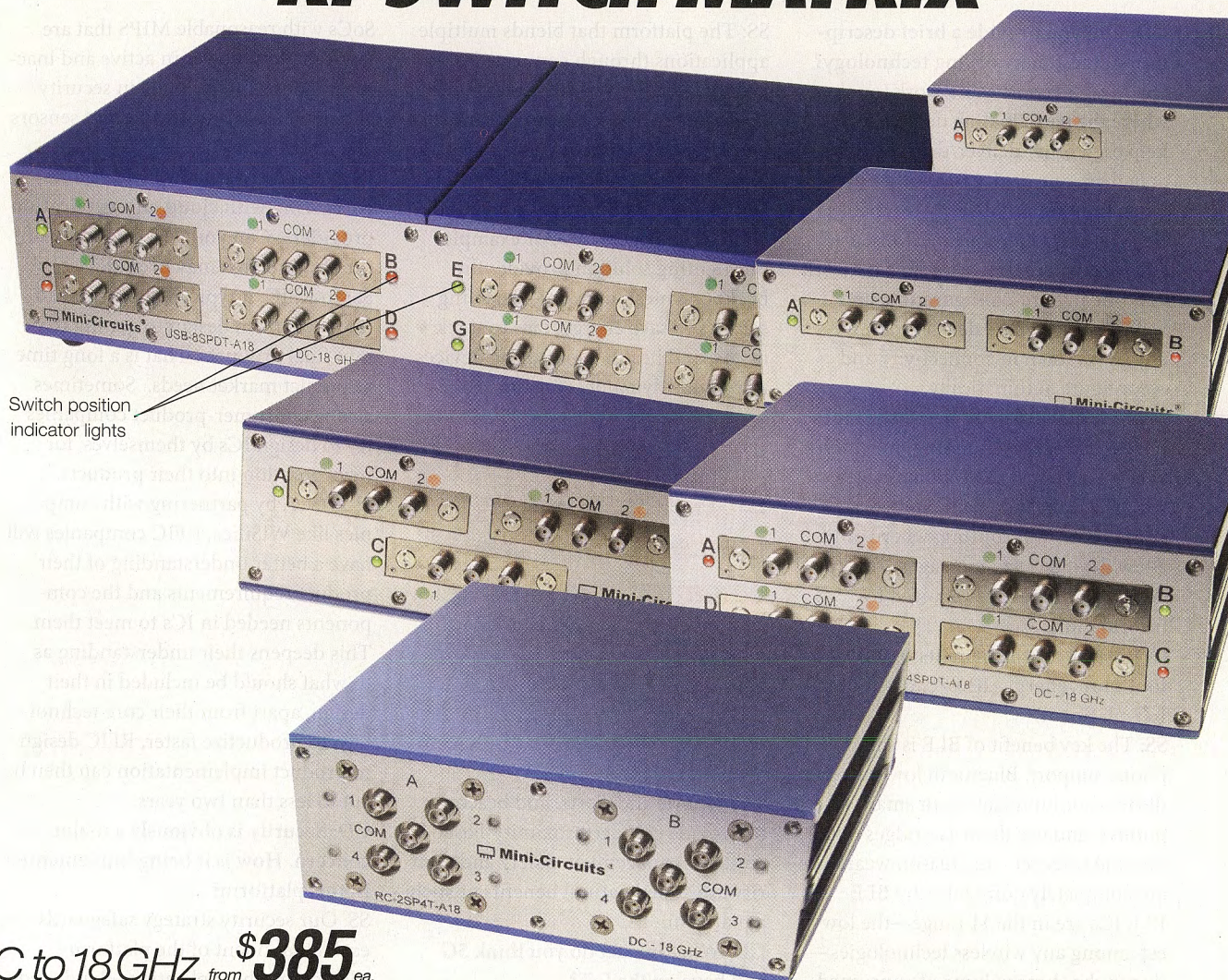
CD: You mentioned RFIC vendors partnering with cloud and application providers. Can you describe some of the benefits this may provide?

SS: In RFIC, it typically takes four to five years from design to getting ICs into final products. That is a long time to predict market needs. Sometimes strong consumer-product companies try to design ICs by themselves, for incorporation into their products. However, by partnering with companies like WiSilica, RFIC companies will have a better understanding of their product requirements and the components needed in ICs to meet them. This deepens their understanding as to what should be included in their design, apart from their core technology, to productize faster. RFIC design to product implementation can then be cut to less than two years.

CD: Security is obviously a major concern. How is it being implemented in this platform?

SS: Our security strategy safeguards each component of the platform (device, mesh, application, cloud, and data). It also provides secure communication, authentication and access control for local/remote command and control operations, along with data gathering and analysis. Components are built from the ground up with security in mind. Cloud servers and mobile applications communicate with each other using the SSL. Communication between device and application uses BLE secure communication with AES 128 bit encryption. All operations performed go through authentication and access control. Data at the cloud server is only accessible through WiSilica's API. Our communication platform is built to prevent the three R's of security issues: readability, repeatability, and replicability. **mw**

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USB-2SPDT-A18	2	0.25	1.2	85	10	685.00
USB-3SPDT-A18	3	0.25	1.2	85	10	980.00
USB-4SPDT-A18	4	0.25	1.2	85	10	1180.00
USB-8SPDT-A18	8	0.25	1.2	85	10	2495.00

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Model	# Switches (SPDT)	IL (dB)	VSWR (:1)	Isolation (dB)	RF P _{MAX} (W)	Price \$ (Qty. 1-9)
RC-1SP4T-A18	1 (SP4T)	0.25	1.2	85	2	895.00
RC-2SP4T-A18	2 (SP4T)	0.25	1.2	85	2	2195.00
RC-1SPDT-A18	1	0.25	1.2	85	10	485.00
RC-2SPDT-A18	2	0.25	1.2	85	10	785.00
RC-3SPDT-A18	3	0.25	1.2	85	10	1080.00
RC-4SPDT-A18	4	0.25	1.2	85	10	1280.00
RC-8SPDT-A18	8	0.25	1.2	85	10	2595.00

*The mechanical switches within each model are offered with an optional 10 year extended warranty. Agreement required. See data sheets on our website for terms and conditions. Switches protected by US patents 5,272,458; 6,650,210; 6,414,577; 7,633,361; 7,843,289; and additional patents pending.

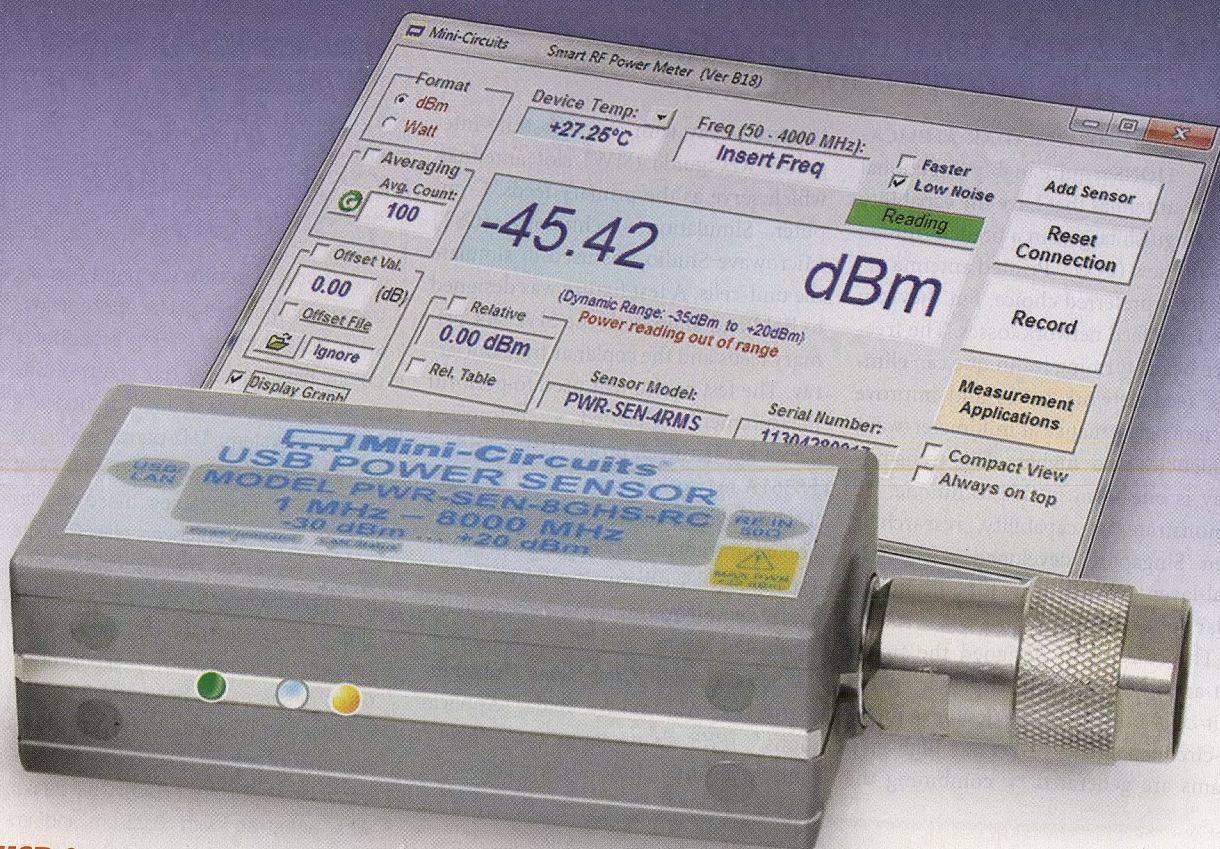
†See data sheet for a full list of compatible software.

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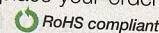
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*Measurement speed as fast as 10 ms for model PWR-8-FS. All other models as fast as 30 ms.

†Dynamic range as wide as -35 to +20 dBm for model PWR-4RMS. All other models as wide as -30 to +20 dBm.

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DUAL-LAYER TRANSMIT-ARRAY POWERS AUTOMOTIVE RADAR

AUTOMOTIVE RADAR APPLICATIONS require highly directional antennas that have the capability to distinguish targets in a predetermined field-of-view (FOV). Printed antenna arrays are a preferred choice, but they can have large feed network losses. The free-space beam-forming technique can eliminate feed network losses and improve antenna performance at millimeter-wave frequencies and higher. The transmit-array is one form of this technique. To demonstrate its capability, researchers from Singapore developed a 77-GHz dual-layer transmit-array for automotive radar applications.

The researchers designed the transmit-array by etching coplanar patch unit-cells on opposite sides of a printed-circuit board (PCB). Four high-gain beams are generated by combining the

transmit-array with four substrate-integrated waveguide (SIW) slot antennas, which serve as the primary feeds. Computer Simulation Technology (CST) Microwave Studio was used to simulate the unit-cells. A test fixture was designed to hold and align both the SIW slot primary feeds and the coplanar transmit-array. The test equipment used to perform measurements included a customized Cascade Microtech probe station and an E8361A network analyzer from Keysight Technologies. The measured gain of the coplanar transmit-array antenna prototype was 18.5 dBi for the ports at 76.5 GHz, demonstrating agreement with the simulated results.

See "77-GHz Dual-Layer Transmit-Array for Automotive Radar Applications," *IEEE Transactions on Antennas and Propagation*, June 2015, p. 2833.

FREQUENCY-SELECTIVE STRUCTURE ACHIEVES WIDE TUNING RANGE

TUNABLE FREQUENCY-SELECTIVE SURFACES can be used to achieve tunable filters for multi-band reflector antennas, tunable radar absorbers, or to provide a varying transmission window in radomes. To generate a dynamic frequency behavior, the reactive characteristics of the surface must change with a tuning voltage, biasing magnetic field, or changing shape. A new three-dimensional (3D) frequency-selective structure (FSS) was designed by a group of researchers from China and Singapore.

The structure is based on a two-dimensional periodic array of vertical varactor-loaded microstrip line resonators and horizontal metallic plates. The biasing circuit of the individual varactor diodes consists of an RF choke and a direct-current (DC) blocking circuit. A 0.813-mm-thick Rogers 4003 substrate was used for the design. The

design goals included a tuning range from 1.40 to 2.75 GHz as well as a fractional bandwidth of 14% at 2.75 GHz. With the help of the High Frequency Structure Simulator (HFSS) software, the parameters for the final layout were determined.

A silicon abrupt varactor diode with a nominal zero-bias junction capacitance between 0.5 and 0.6 pF was selected for the design. The tunable 3D FSS was measured inside a parallel-plate waveguide structure. The measured return loss was greater than 10 dB across the entire tuning range. While varying the bias voltage from 0 to 30 V, the center frequency was tuned from 1.40 to 2.75 GHz. The insertion loss across the frequency range varied from 1.0 to 4.5 dB.

See "Tunable 3-D Bandpass Frequency-Selective Structure with Wide Tuning Range," *IEEE Transactions on Antennas and Propagation*, July 2015, p. 3297.

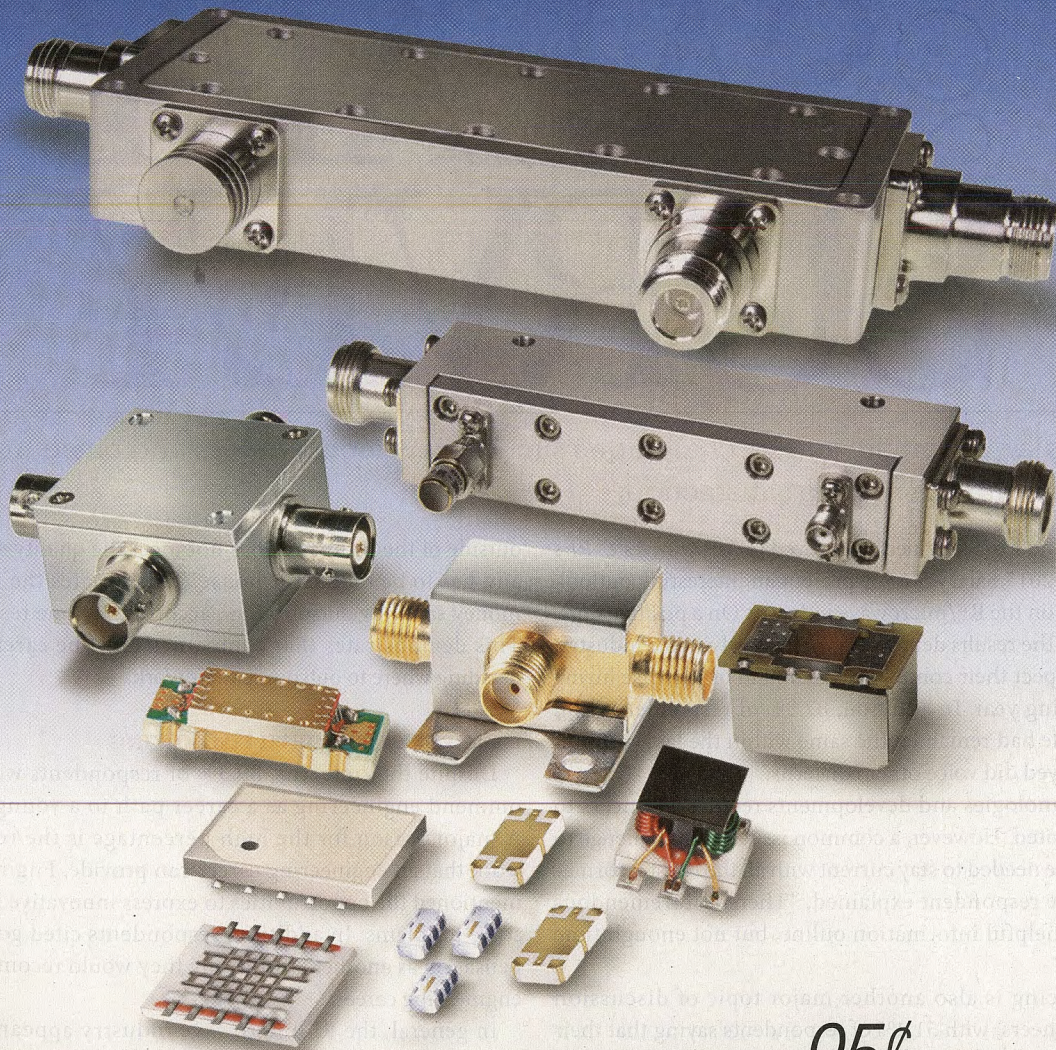
TERAHERTZ VOLTAGE-CONTROLLED OSCILLATOR INCORPORATES COUPLED-LINE TOPOLOGY

THE 300-GHZ FREQUENCY band has attracted growing interest for applications, such as terahertz (THz) broadband communications and THz imaging. Because an oscillator is a key component in a THz system, THz-band oscillators have received an increasing amount of attention. In recent times, these oscillators have been achieved with Colpitts or common-base coupling topologies. By implementing a new coupled-line structure based on the common-emitter cross-coupled topology, a group of researchers from the School of Electrical Engineering, Korea University have developed a new THz-band voltage-controlled oscillator (VCO). The design was achieved with 0.25- μ m indium-phosphide (InP) heterojunction-bipolar-transistor (HBT) technology.

Two measurement setups were used to characterize the oscillator. A spectrum analyzer performed the task of measuring the oscillation frequency and the phase noise. The oscillation frequency was tuned from 309.5 to 339.5 GHz by varying V_{BE} from 1.0 to 1.4 V. When the oscillation frequency was tuned to 317.5 GHz, the measured phase noise was -86.55 dBc/Hz at 10 MHz offset. Secondly, a power meter was used to measure the oscillator's output power. This was measured over the entire V_{BE} tuning range from 1.0 to 1.4 V. The results demonstrated a maximum output power level of -6.5 dBm at 334 GHz. In addition, the oscillator's power dissipation was 13.5 mW.

See "A 310-340-GHz Coupled-Line Voltage-Controlled Oscillator Based on 0.25- μ m InP HBT Technology," *IEEE Transactions on Terahertz Science and Technology*, July 2015, p. 652.

Directional / Bi-Directional COUPLERS



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2015 MICROWAVES & RF SALARY SURVEY

While salaries remain stable, challenges such as new technologies and outsourcing are impacting overall job satisfaction.

The 1,659 engineers surveyed in *Microwaves & RF's* 2015 Salary Survey present an interesting outlook on the RF/microwave industry. On a positive note, the results demonstrate a relatively stable industry, as 89.2% expect their company to maintain or increase hiring in the coming year. In addition, 87.9% of respondents said their job title had remained the same within the last year. But those surveyed did voice other concerns.

New technologies and developments require engineers to remain updated. However, a common issue is the challenge to find the time needed to stay current with all the latest information. As one respondent explained, "There is a tremendous amount of helpful information online, but not enough time to utilize it."

Outsourcing is also another major topic of discussion among engineers, with 51.4% of respondents saying that their company does indeed outsource engineering work. The primary reasons for outsourcing vary, but cost savings as well as the lack of highly specialized in-house skills appear to be prevalent factors. Personal opinions of outsourcing are quite varied. Some point out its potential negative effects, while others believe it can actually reap benefits—for instance, by allowing a company to focus on its core competencies. As one respondent said, "Outsourcing is what allows us to focus all our efforts on the core design. It increases our know-how in the areas that the company has decided not to outsource."

The actual quality of outsourced work was also mentioned. "Outsourcing can be beneficial. But sometimes the work done

outside of the company does not meet the quality standards and has to be redone in-house. This negates the time and money saved by outsourcing," according to one respondent. This demonstrates that companies must be careful when deciding where to outsource their work.

A CAREER PATH WORTH FOLLOWING

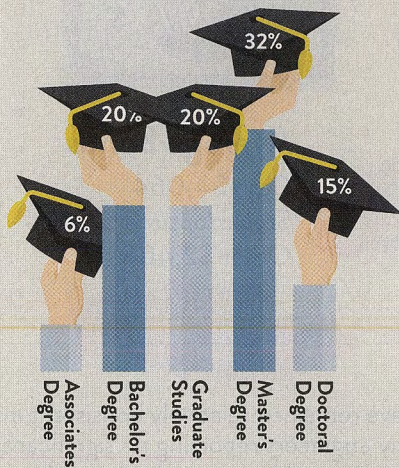
Despite the concerns, 89.3% of respondents would recommend engineering as a career path to a young person. A major reason for the high percentage is the rewarding work that an engineering career can provide. Engineers also mentioned the opportunities to express innovative ideas and solve problems. In addition, respondents cited good compensation as another reason why they would recommend an engineering career.

In general, the RF/microwave industry appears to look positive, with 88.3% of respondents saying they are satisfied in their current position. Engineers also reported an average base salary of \$100,657, with 66.7% saying they felt adequately compensated for their work. Overall, the industry appears to be in good shape. Engineers remain well compensated for their innovative and challenging work—and with a generally high level of job satisfaction, the profession should remain strong for the foreseeable future. **MTW**

TECHNICAL EDITOR CHRIS DEMARTINO wrote this report. Data conducted and compiled by Jay McSherry. For the complete report online, visit www.mwrf.com.

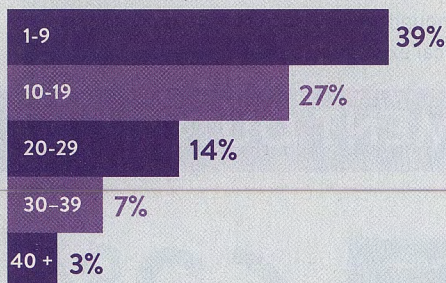
THE TYPICAL ENGINEER

Highest education level

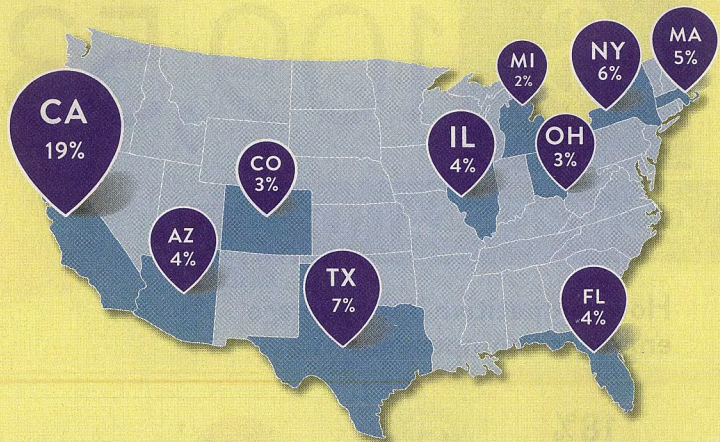


"This is probably one of the hardest fields to become proficient in, yet can be so incredibly fulfilling if one is committed to a lifetime of learning," said one respondent.

Years at present company

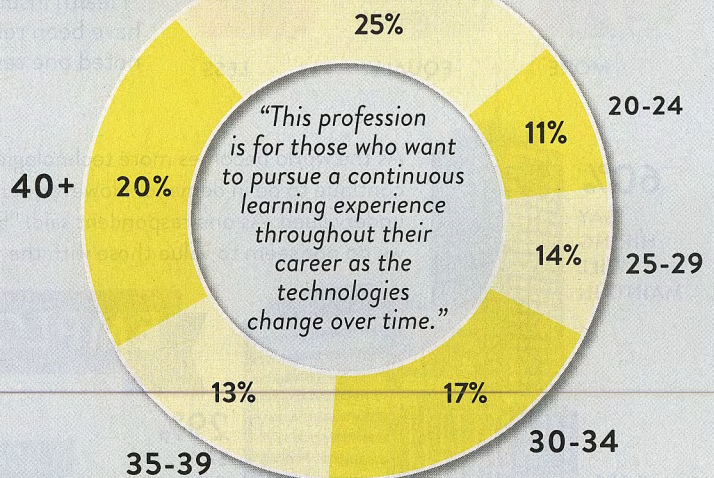


Work locations



Years in the profession

Under 20



Age

The RF/microwave engineering workforce is aging, as many older engineers are inching closer to retirement. As a result, younger engineers will have the opportunity to fill many senior-level engineering positions. As one respondent declared, "The engineering workforce is aging and opens opportunities for young engineers to join and learn from the best. They can then fill the senior engineers' positions when they retire. And with the push for new technologies, young engineers can use their knowledge and excitement to pursue various areas of engineering."

25-34



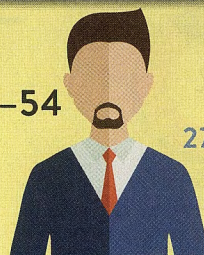
6%

35-44



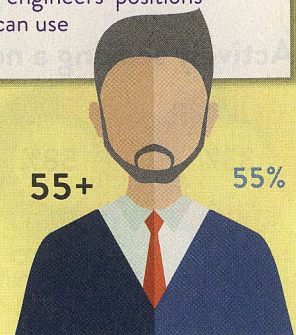
11%

45-54



27%

55+



55%



\$

Average Compensation

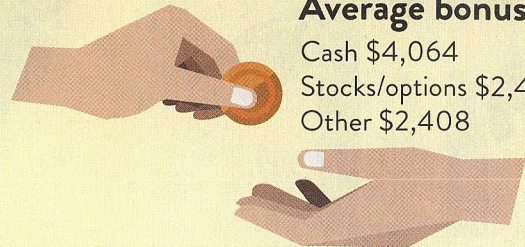
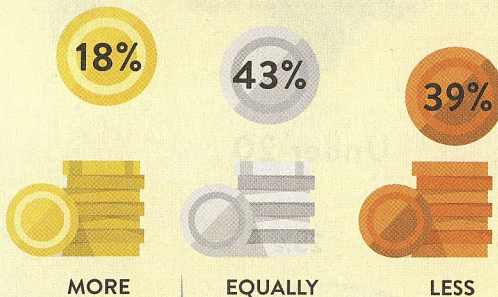
109,533

Average compensation increase

\$ 1.29% \$

COMPENSATION

How competitive is the average engineer's compensation?



Average bonus

Cash \$4,064
Stocks/options \$2,404
Other \$2,408

Engineering salaries have remained relatively consistent in recent years, with many engineers reporting no significant changes in their compensation. However, a large number of engineers reported increased health insurance costs. "Health insurance goes up slightly each year while salaries have been relatively constant for the last five to six years," noted one respondent.

60%
SAY
HIRING
WILL
MAINTAIN

11%
SAY
HIRING
WILL
REDUCE

29%
SAY
HIRING
WILL
GROW

As the world becomes more technological, engineers remain positive that their skills will continue to be in demand. However, some engineers also believe their contributions are undervalued. As one respondent said, "Even though we as a society love our gadgets, we do not seem to value those with the technical expertise to create them."

EMPLOYMENT OUTLOOK

Is an engineering career as promising today as it was five years ago?

62%
SAY YES

"Over the last five years, I don't think there has been as much of a change in the market as, say, 15 years ago."

Actively seeking a new position



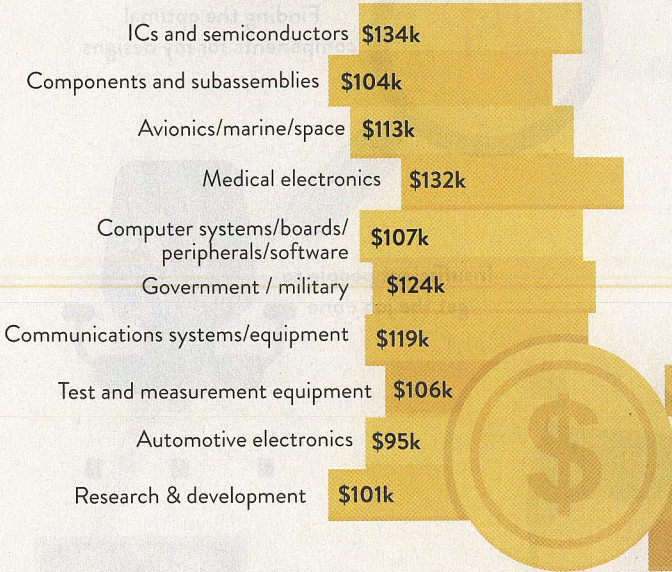
Is your organization more focused on employee retention this year?



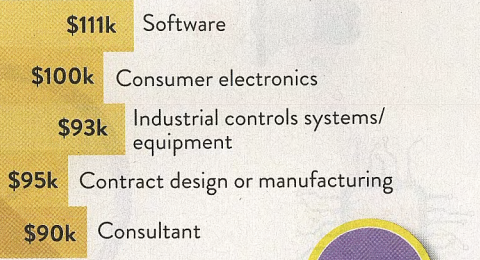
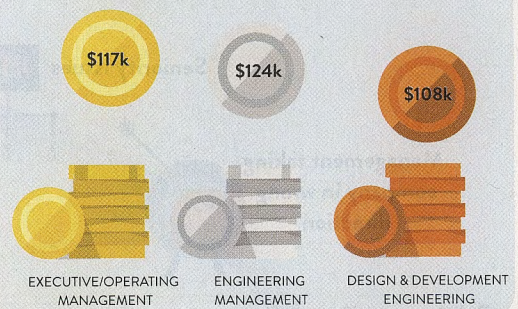


COMPENSATION BREAKDOWN

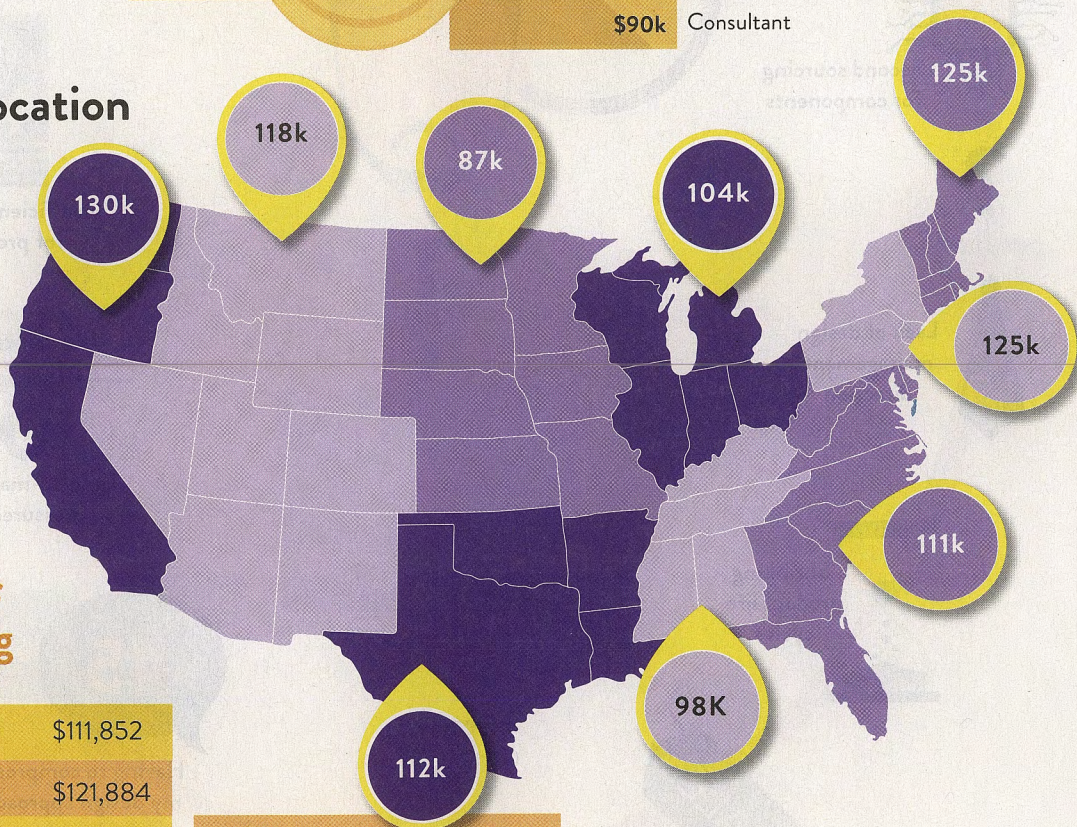
By industry



By job function



By location

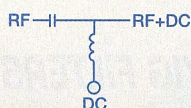
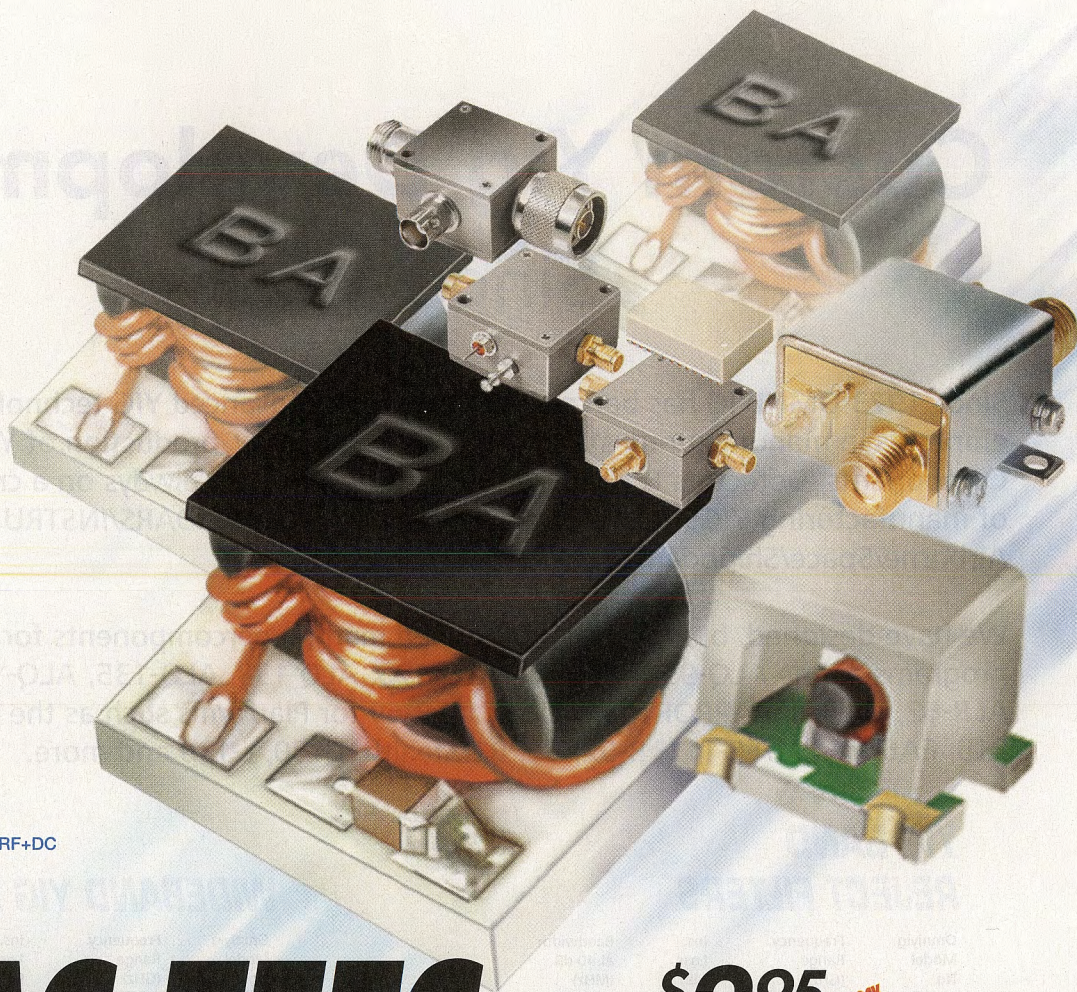


By years of engineering experience

40 years or more	\$111,852	15-19 years	\$113,944	1-4 years	\$75,026
35-39 years	\$121,884	10-14 years	\$85,350	Less than 1 year	\$74,889
30-34 years	\$123,053	5-9 years	\$72,044		
25-29 years	\$113,593				
20-24 years	\$106,979				

CONCERNS AT WORK





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Mini-Circuits is your complete source for Bias-Tees, covering from 100 kHz to 12 GHz and handling up to 4A DC in a variety of coaxial and surface mount packages. All of our Bias-Tees provide low insertion loss and VSWR. Our patented TCBT LTCC ceramic designs are the smallest in the industry and are suitable for projects where low price, small size, and temperature stability are a must. Our ultra-wideband ZX85 Bias-Tees use our patented unibody construction affording small size and high repeatability. Whether your applications call for biasing amplifiers, laser diodes, or active antennas, DC blocking, DC return, satellite communications, test, or if you have custom requirements, just contact Mini-Circuits and let us fit your needs to a "TEE"!



RoHS compliant.

TYPICAL SPECIFICATIONS

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	Max Current mA	Price \$ea. Qty. 10
TCBT-2R5G+**	20-2500	0.35	44	200	6.95
TCBT-6G+**	50-6000	0.7	28	200	7.95*
TCBT-14+***	10-10000	0.35	33	200	8.45
TCBT-14R+***	10-10000	0.6	33	200	8.45

TCBT: LTCC. Actual Size .15" x .15"

U.S. Patent 7,012,486**

U.S. Patent 8,644,029***

Model	Freq (MHz)	Insertion Loss (dB)	Isolation (dB)	Max Current mA	Price \$ea. Qty. 1-9
JEFT-4R2G+	10-4200	0.6	40	500	39.95
JEFT-4R2GW+	0.1-4200	0.6	40	500	59.95
PBTC-1G+	10-1000	0.3	33	500	28.20
PBTC-3G+	10-3000	0.3	30	500	38.20
PBTC-1GW+	0.1-1000	0.3	33	500	38.20
PBTC-3GW+	0.1-3000	0.3	30	500	49.20
ZFBT-4R2G+	10-4200	0.6	40	500	59.95
ZFBT-6G+	10-6000	0.6	40	500	79.95
ZFBT-4R2GW+	0.1-4200	0.6	40	500	79.95
ZFBT-6GW+	0.1-6000	0.6	40	500	89.95
ZFBT-4R2G-FT+	10-4200	0.6	N/A	500	79.95
ZFBT-6G-FT+	10-6000	0.6	N/A	500	79.95
ZFBT-4R2GW-FT+	0.1-4200	0.6	N/A	500	79.95
ZFBT-6GW-FT+	0.1-6000	0.6	N/A	500	89.95
ZFBT-282-1.5A+	10-2800	0.6	45	1500	59.95
ZFBT-352-FT+	30-3500	0.4	23	4000	49.95
ZNBT-60-1W+	2.5-6000	0.6	45	500	82.95
ZX85-12G+	0.2-12000	0.6	N/A	400	99.95

ZX85: U.S. Patent 6,790,049.

Note: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.

*Price is for quantity of 20



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Since 1973 OMNIYIG has been on the forefront of advanced YIG technology with emphasis in manufacturing state-of-the-art technology, production of YIG Components, Detectors & Limiters. We, at OMNIYIG, are always on a critical mission of manufacturing YIGS for all EW/ECM/ECCM/JAMERS/RADARS/INSTRUMENTS for Airborne/Space/Shipboard...

We have designed, built and manufactured many supercomponents for such programs as the ALQ-99, ALQ-117, ALQ-125, ALQ-133, ALQ-135, ALQ-172, ALR-56C, ALR-62, WLR-8, RAPPORT III, ALR-67/ALR-69 for Platforms such as the F-15, F-16, F18, EA6B, F111/EF-111, B-52, B1, B2 Stealth, C130, L-130 and more.

YIG BAND REJECT FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 40 dB (MHz)
M107RX	8.0 - 18.0	1.5	20
M104RX	4.0 - 18.0	2.0	8
M105RX	2.0 - 8.0	1.5	10

MIL-SPEC and High Reliability!
Integrated with Analog and 12 Bit Digital Drivers.
MANY other Multioctave designs available.

WIDEBAND YIG FILTERS

Omniyig Model No.	Frequency Range (GHz)	Ins. Loss (dB)	Bandwidth at 3 dB (MHz)
4-STAGE			
M3064	6.0 - 18.0	6.5	500 min
M2997	6.0 - 18.0	6.0	400 min
M3513	8.0 - 18.0	6.5	500 min

Industry-leading bandwidths in multi-octave, YIG units providing the widest 3dB bandwidth available!

YIG MULTIPLIERS

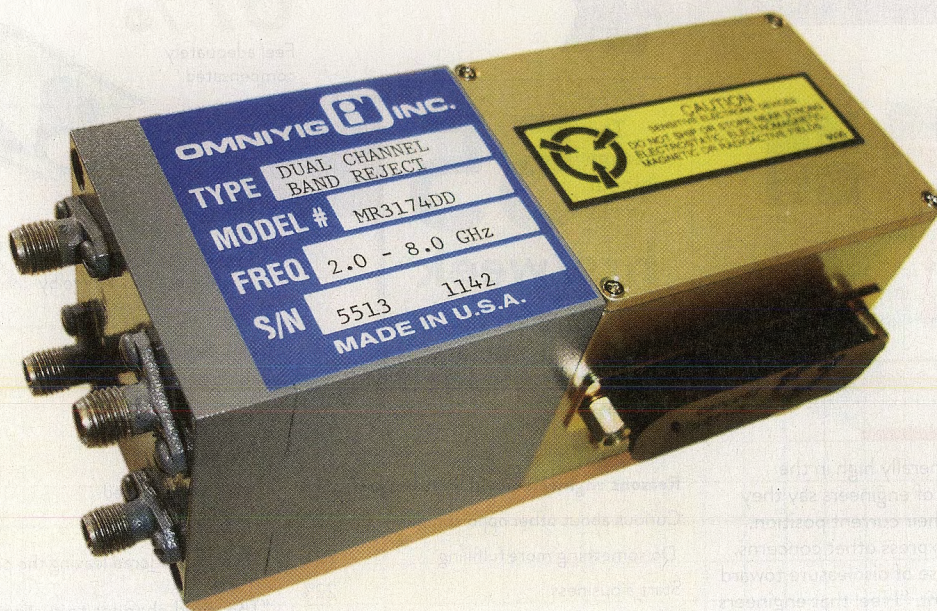
Omniyig Model No.	Input Frequency (GHz)	Output Frequency (GHz)	Output Power (dBm)
YM1001	1.0 - 2.0	2.0 - 13.0	6
YM1002	0.1	1.0 - 12.0	-33
YM1003	0.2	1.0 - 12.0	-28
YM1004	0.5	1.0 - 12.0	-10
YM1026	1.0 - 2.0	2.0 - 18.0	-4
YM1027	0.1	1.0 - 18.0	-40
YM1028	0.2	1.0 - 18.0	-33
YM1029	0.5	1.0 - 18.0	-22
YM1087	0.1 - 0.2	1.0 - 12.0	-25

RF input power on all models 0.5 to 1.0 watts.
Fast switching, MIL-Spec Hi-Reliability and units integrated with drivers, oscillators or amplifiers also available.

LOW PHASE NOISE YIG OSCILLATORS

Omniyig Model No.	Frequency Range (GHz)	RF Power Output (mW)	Second Harmonic (dBc)
YOM1517	0.5 - 2.0	20-60	16
YOM1518	1.0 - 4.0	20-60	16
YOM1514	4.0 - 12.0	10	15
YOM3719-5	2.0 - 15.0	20	13
YOM1679	2.0 - 12.4	20	13
YOM83	2.0 - 6.0	20	12
YOM137	2.0 - 8.0	20	12
YOM3719-4	8.0 - 18.0	20	14
YOM3719-2	6.0 - 18.0	20	14
YOM3719-1	4.0 - 18.0	20	13
YOM3719	3.0 - 18.0	10	12
YOM3676	2.0 - 18.0	20	15

We offer other models with Second Harmonic -60 dBc and Oscillators integrated with 2-stage YIG Filters.



STANDARD DETECTORS

Omniyig Model No.	Frequency Range (GHz)	k Factor	TSS (dBm)
Zero-Bias Schottky			
ODZ0004A	0.1 - 18.0	1200	-52
ODZ0328A	2.0 - 18.0	1200	-52
ODZ0441A	6.0 - 26.0	1000	-51

STANDARD COMB GENERATORS

Omniyig Model No.	Input Frequency (MHz)	Output Frequency (GHz)	Output Power (dBm)
OHG10118	100	0.1 - 18.0	-40
OHG20218	20	0.2 - 18.0	-35
OHG51026	500	0.5 - 18.0	-28
OHG81026	1000	1.0 - 18.0	-18

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STANDARD LIMITERS

Omniyig Model No.	Frequency Range (GHz)	Insertion Loss (dB)	Leakage Power (dBm)
Pin			
OLP2645A	8.0 - 18.0	2.0	+19
OLP2726A	2.0 - 18.0	1.2	+19
PL473	0.5 - 12.0	1.8	+19
OLP2652	2.0 - 18.0	2.5	+20
Schottky Turn-on			
SL048	2.0 - 26.0	2.5	+14
OLD2635A	4.0 - 18.0	2.5	+14
OLD2733A	0.4 - 18.0	2.5	+14

Leakage Power Measured at P(in) = +30 dBm

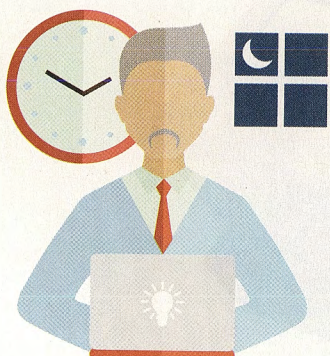
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JOB SATISFACTION



Job satisfaction is generally high in the industry, as only 12% of engineers say they are unsatisfied with their current position. However, some did express other concerns. Among them is a sense of displeasure toward company management. "I feel that engineers are worked hard and paid well, but the magnitude of the effort is never appreciated by upper management and marketing types that never set foot in the lab door," said one respondent.

The average engineer works **55 hrs/week** at the office and at home and other locations

Reasons engineers would leave the profession

Curious about other opportunities	30%
Do something more fulfilling	22%
Start a business	22%
Do something less stressful	21%
Ready to retire	17%
No further chance for advancement	16%
Switch to teaching	13%

67%

Feel adequately compensated



Feel compensation should increase on average by

22%

Job Satisfaction

Extremely satisfied	21%
Very satisfied	30%
Satisfied	37%
Not very satisfied	10%
Not at all satisfied	2%
Have considered leaving the profession	34%

"The rapid changes to systems and components require new skills and, hence, engineers who are adaptable. Those who can and do keep up with the technology have great, albeit challenging opportunities."

Most important factors in job satisfaction

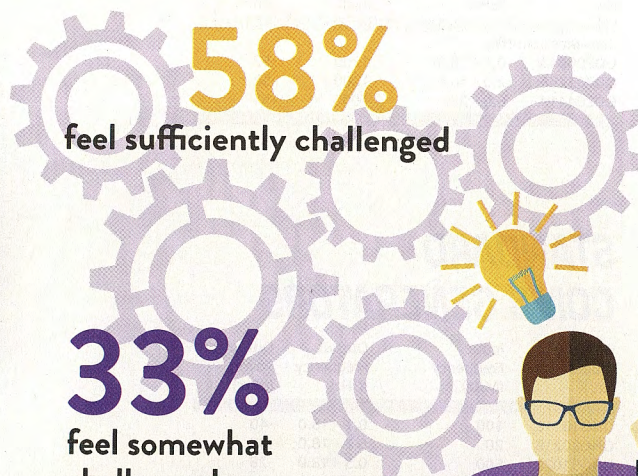
1. Researching potential design solutions
2. Challenges that accompany the design of new products
3. Opportunity to design products that can benefit society
4. The compensation you receive for the work you do
5. Working in team situations with peers
6. The recognition you get from others for the work you do
7. Working independently of others
8. The pressures associated with solving design problems



ENGINEERS TALKING FROM THE PULPIT

"Engineering is a stimulating career that offers many opportunities for creativity. It's challenging and always changing. Engineering also develops problem-solving skills that are widely applicable as well as providing great opportunities to work in teams."

"The quantitative skills learned in engineering can be applied to many other areas. It also indicates that someone is able to learn additional skills."



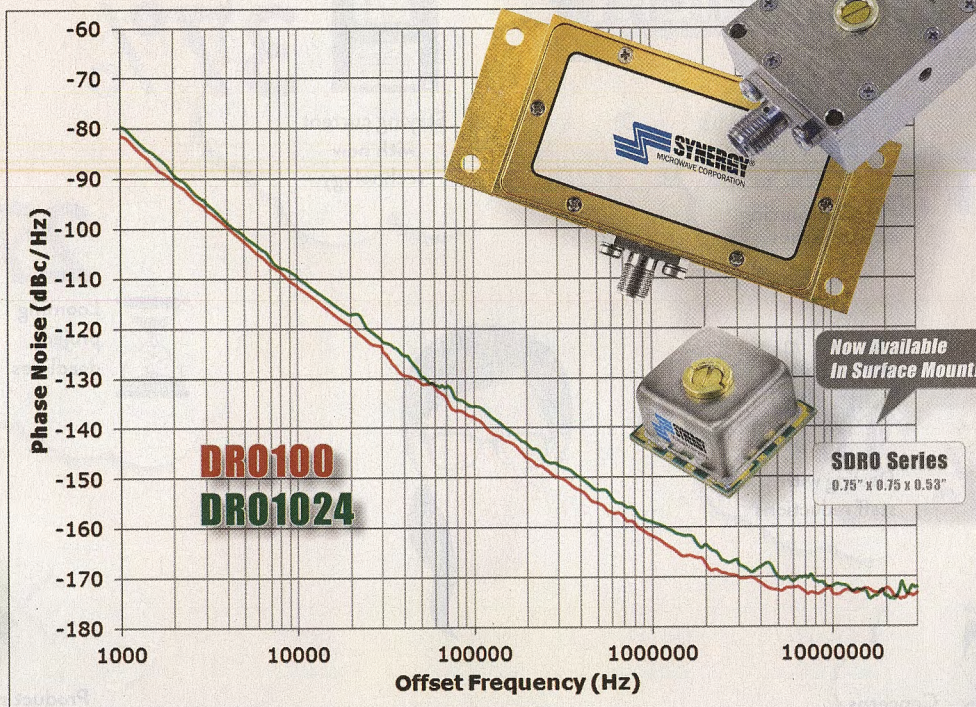
89%

would recommend the profession to a young person



Exceptional Phase Noise Performance Dielectric Resonator Oscillator

RoHS Patented
Technology



Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @10kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10	1 - 15	+7 - 10 @ 70 mA	-109

Model	Center Frequency (GHz)	Mechanical Tuning (MHz)	Supply Voltage (VDC / Current)	Typical Phase Noise @10kHz (dBc/Hz)
Mechanical Tuning Connectorized Model				
KDRO145-15-411M	14.5	±10 MHz	15 V / 130 mA (Max.)	-88

Talk To Us About Your Custom Requirements.



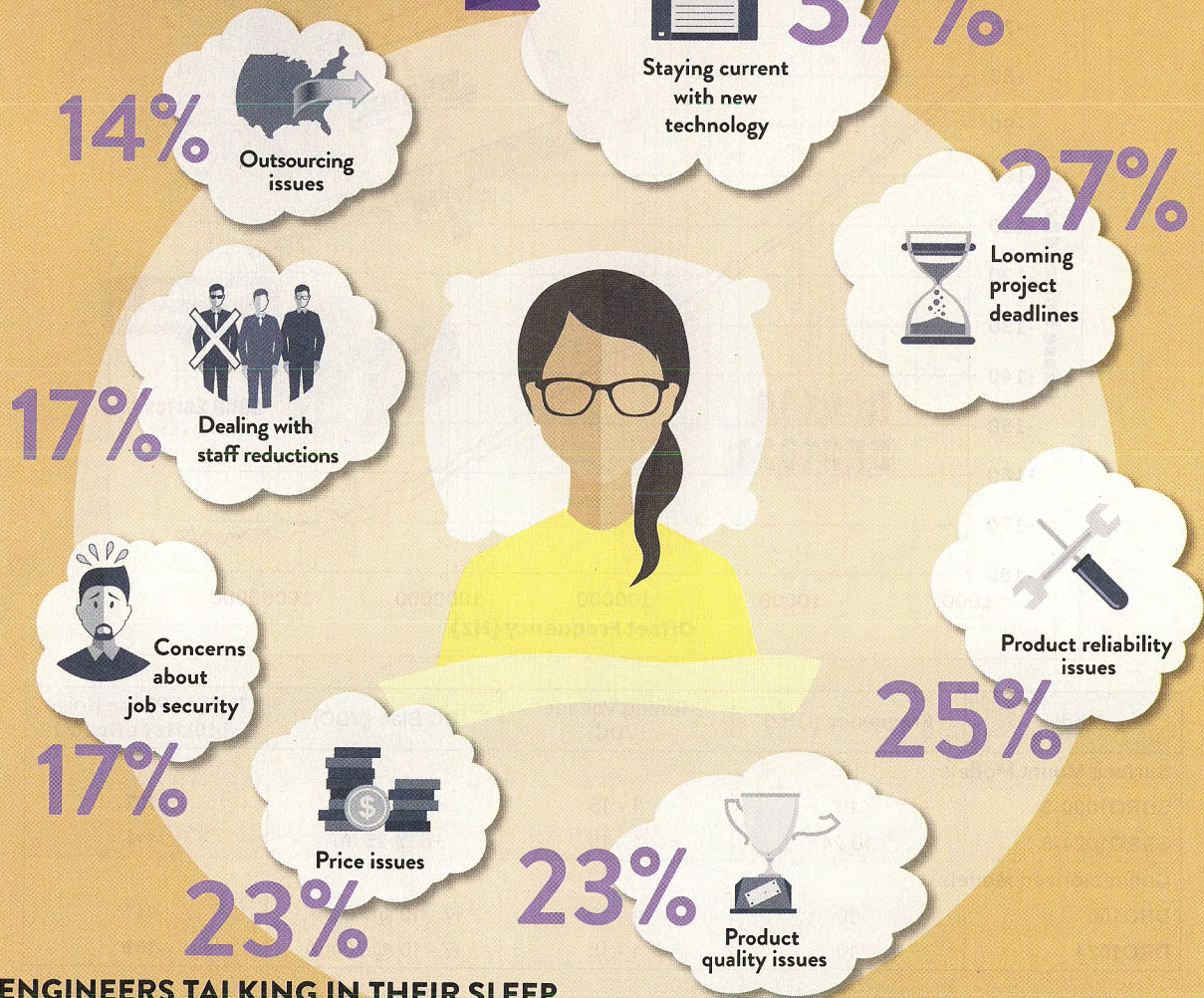
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ISSUES KEEPING

ENGINEERS

UP AT NIGHT

Engineers commonly say they have insufficient time to stay current with technology. Many struggle to consume the vast amount of available information.



ENGINEERS TALKING IN THEIR SLEEP

"Discovering new technologies and getting enough information about them to determine if they are relevant to my work is a challenge."

"Useful, instructive information on some areas of design is incredibly hard to find."

"There is never enough time in the day to just read engineering publications that interest me."

"Greed and the bottom line drive all ethics in development. Business needs to override good design and product development. We are constantly under pressure to 'just ship it.'"

Make RF Smarter with Freescale.

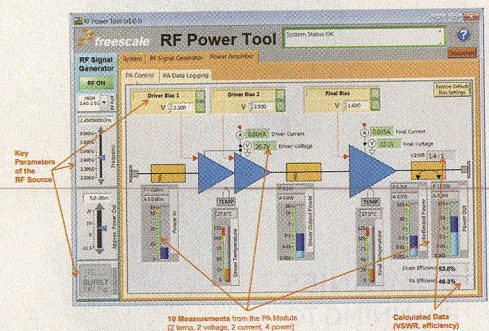
Leverage the benefits of solid-state RF Energy with Freescale's RF Power Tool



Engage RF Power transistors with:

- ✓ Intuitive PC-based user interface
- ✓ 10 MHz – 3 GHz integrated signal generator
- ✓ 10 measurements points, such as transistor temperature, output and reflected power
- ✓ Built-in safety features: warning and shutdown thresholds

Visit Freescale.com/RFpowertool



The RF Power Tool dramatically simplifies prototyping with RF Power transistors, without the need for an expensive rack of test equipment or extensive technical knowledge.

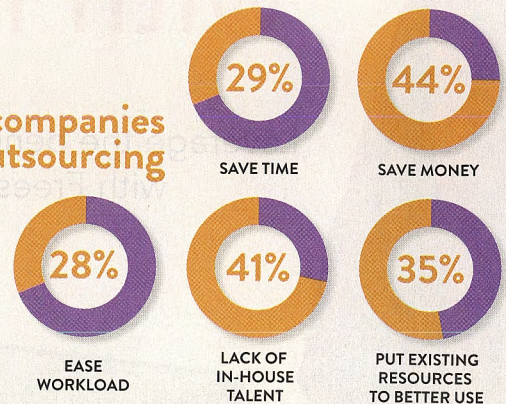
This versatile bench-in-a-box combines every function required to evaluate an RF transistor in a single instrument. The friendly PC interface provides a simplified view of a power amplifier, making access to solid-state RF design quick and easy.

THE NECESSARY EVIL OF OUTSOURCING

OPINIONS ON OUTSOURCING

FEWER ENGINEERING JOBS AVAILABLE	41%
LOWER EMPLOYEE MORALE	39%
NEW HIRES AT REDUCED SALARIES	36%
FEWER OPPORTUNITIES FOR ADVANCEMENT	34%
SKILLS VALUED LESS	29%
SALARY REDUCTIONS FOR EMPLOYEES	24%
OPPORTUNITY FOR MORE INNOVATIVE PROJECTS	21%
IMPORTANT ASPECT TO BUSINESS GROWTH	15%
SKILLS VALUED MORE	12%
NEW HIRES TO SUPPORT OUTSOURCING EFFORTS	12%

Reasons companies are outsourcing



Where jobs are going



COMPANIES PLANNING TO OUTSOURCE
7%

With a lack of available resources, companies turn to outsourcing as a necessary means. However, outsourcing raises several concerns among engineers, such as the loss of skills and experience.



51%
OF COMPANIES
OUTSOURCE WORK

JOBS BEING OUTSOURCED

SOFTWARE ENGINEERING/DEVELOPMENT	49%
MANUFACTURING/ASSEMBLY	46%
DESIGN	34%
PCB LAYOUT	33%
R&D	23%
SOFTWARE VERIFICATION/TEST	19%
CAD/CAE	19%
DESIGN VERIFICATION	14%
FINAL TEST	16%
DRAFTING	10%

The Right RF Parts. Right Away.

The image shows a hand holding a silver stopwatch in front of a laptop screen. The laptop screen displays the Fairview Microwave website, which features a grid of various RF components. The website's header includes the company logo, a 'Live Chat' button, and a phone number. The grid of products includes:

- New Products
- Adapters
- Connectors
- Amplifiers
- Attenuators
- Cable Assemblies
- Terminations
- Isolators
- Circulators
- Power Dividers
- Antennas
- Bias Tees
- Shorts & RF Caps
- Couplers

We're RF On Demand, with over one million RF and microwave components in stock and ready to ship. You can count on us to stock the RF parts you need and reliably ship them when you need them. Add Fairview Microwave to your team and consider it done.

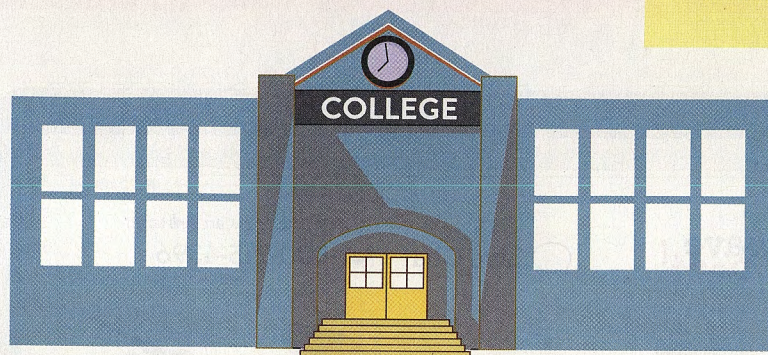
fairviewmicrowave.com
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RF COMPONENTS ON DEMAND. *Done!*



CONTINUING

EDUCATION



Engineers are required to stay current with the latest technology. However, many say they simply don't have enough time to pursue further education. As one respondent noted, "Because I am so busy with work, it can be pretty challenging finding the time for further education." A large number of additional learning resources are available, ranging from publications, white papers, webcasts, and more.

#1 obstacle to staying current with information:

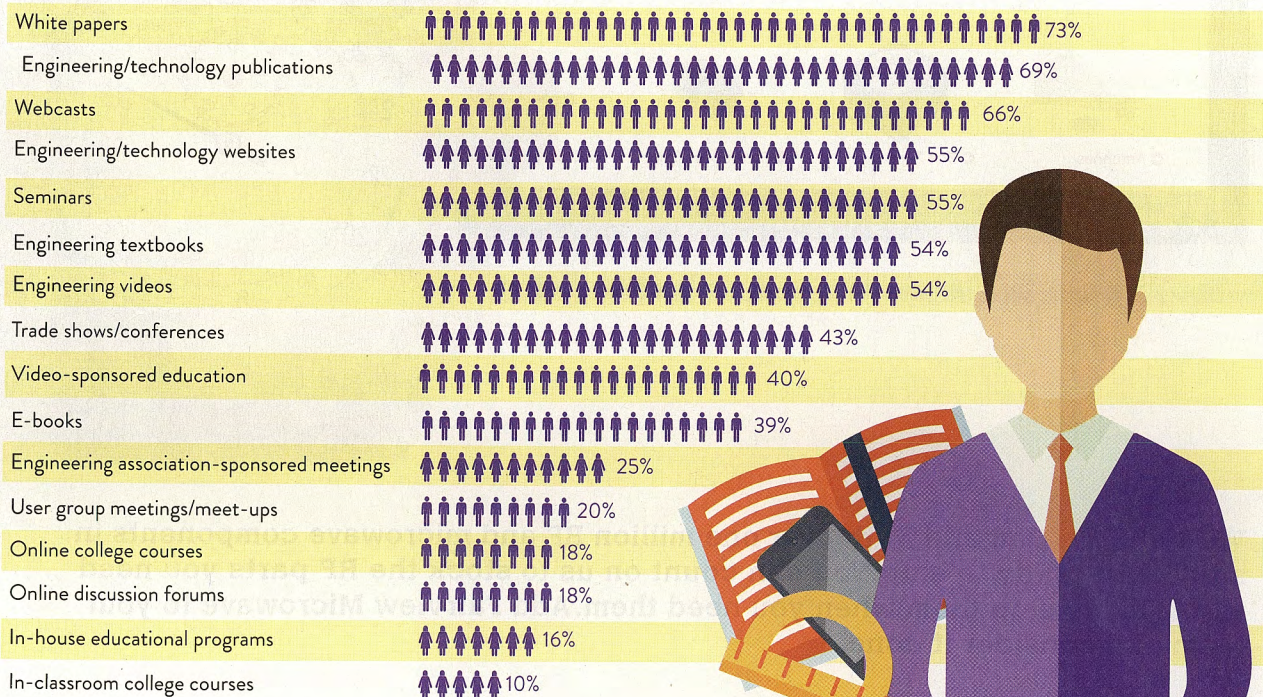


Finding the time.

For which of these forms of education does your company reimburse costs to engineers?

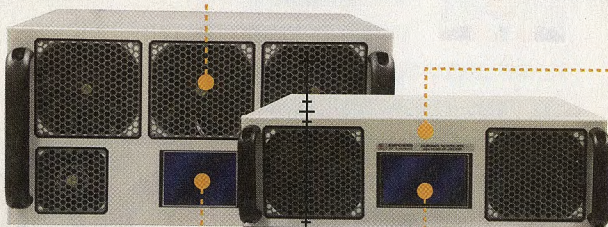
Trade shows/conferences	56%
Seminars	54%
College tuition	36%
Engineering textbooks	37%
Publication subscriptions	28%
Engineering association dues	26%
Certifications	23%
Online training	21%

How engineers are keeping up



POWER AMPLIFIER EVOLUTION

Setting Your Sights
on Smart Power
and Size Reduction

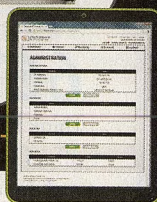


1 kW in 5U

500 W in 3U

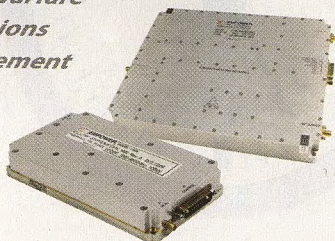
Up to 10 kW pulse

Remote Monitoring & Control
Via Embedded WEB Server



*Electronic Warfare
Communications
Test & Measurement
Radar*

*Ground Mobile
Airborne
Shipboard
Fixed Installation*



Next Generation Power Amplifier Systems

SKU 2126	1 kW	20 - 500 MHz	5U chassis
SKU 2175	500 W	20 - 1000 MHz	3U chassis
SKU 2162	1 kW	20 - 1000 MHz	5U chassis
SKU 2066	1 kW	500 - 1000 MHz	5U chassis
SKU 2180	2 kW	1000 - 2500 MHz	8U chassis
SKU 2170	1 kW	1000 - 3000 MHz	5U chassis
SKU 2179	250 W	2000-6000 MHz	4U chassis

High Performance Building Block Modules

SKU 1163	125 W	20 - 520 MHz	7 x 4 x 1.2"
SKU 1193	100 W	20 - 1000 MHz	7 x 4 x 1.2"
SKU 1199	100 W	1000 - 3000 MHz	7 x 4 x 1.2"
SKU 1178	35 W	2000 - 6000 MHz	6.9 x 3.6 x 1.1"
SKU 1191	100 W	2500 - 6000 MHz	8 x 6.5 x 1"



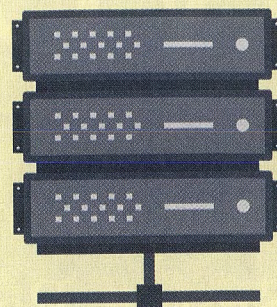
www.EmpowerRF.com

EMPOWER
RF SYSTEMS, INC.

TEST AND MEASUREMENT

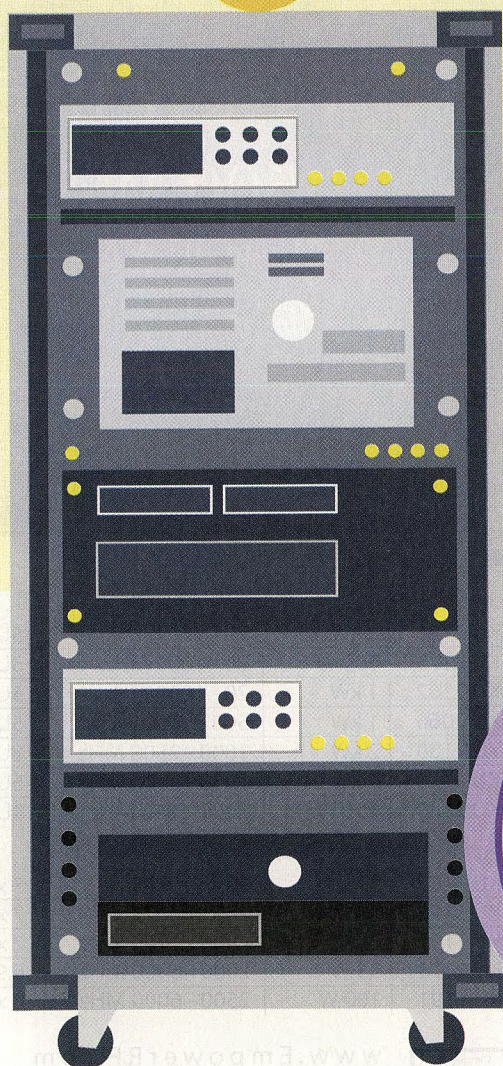
60%

Think their company
invests sufficiently in
test equipment



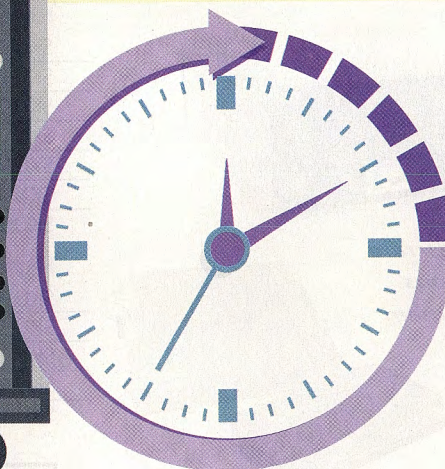
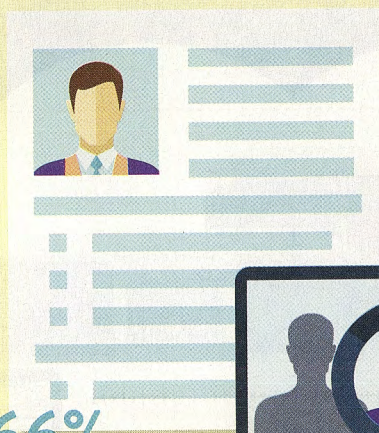
21%

Companies that have
replaced box-test instruments
with modular solutions



66%

Think their company
offers sufficient training
and documentation



64%

Think testing is a
significant challenge
in terms of time
consumption

PREPARING FOR THE INTERNET OF THINGS

53%

of organizations
have difficulty
finding
qualified
candidates



**Engineering specialties
in demand**

17%

**MECHANICAL
DESIGN**

23%

EMBEDDED

26%

DIGITAL

33%

**SYSTEMS
ENGINEERING**

68%

RF

28%

SOFTWARE

22%

POWER

38%

ANALOG



The **Internet of Things** has the potential to have a huge impact, providing connectivity to countless objects. This also may provide engineers with even more opportunities in the days ahead. Because of both today's and tomorrow's technology, engineers can expect to stay in high demand.

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from

JFW



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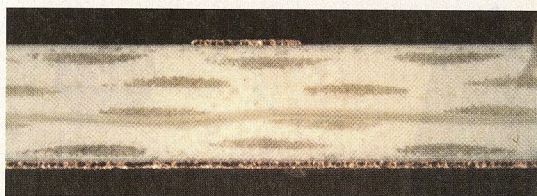
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Control Crosstalk in RF/Microwave Systems

Crosstalk can cause serious performance degradation in high-frequency analog and high-speed digital circuits, but smart design decisions will help minimize that nemesis.



1. This microstrip transmission line was fabricated on 20-mil-thick RO4003C laminate from Rogers Corp. (www.rogerscorp.com) with dielectric constant of 3.38 at 10 GHz. (Courtesy of Rogers Corp.)

SIMPLY PUT, CROSSTALK will generally wreak havoc on high-frequency circuits and systems. These include simple devices such as radio integrated circuits (ICs), in which transmitted signals aren't properly shielded from or directed away from the receiver circuitry. Or it can deleteriously affect more complex, multiple-channel communications systems, in which signals from one channel may leak over to another channel.

RF/microwave crosstalk is essentially the unwanted conducting of high-frequency signals from one part of a system to another. It disrupts system operation, and must be avoided as much as possible through effective measurement and appropriate design practices.

High-frequency transceivers are susceptible to crosstalk because of an architecture that typically employs a high-output-level local oscillator (LO) with a frequency mixer and RF and intermediate-frequency (IF) amplifiers to perform frequency conversion. The LO is often based on a tunable oscillator, such as a voltage-controlled oscillator (VCO) or a YIG oscillator, and can radiate or leak signal energy that becomes conducted by nearby transmission lines in a circuit or system.

To complicate matters, depending on the circuit layout, transmission lines in parallel that are very closely spaced (to form compact circuitry) can perform like antennas for signal energy conducted from, say, a high-energy source (e.g., an LO and "receive" energy from the source or from nearby transmission lines). As a result, it will conduct that energy into components such as amplifiers, which have elevated crosstalk-signal amplitude levels.

CROSSTALK ENABLERS

RF/microwave circuits are susceptible to crosstalk due to numerous factors, including type of transmission line—microstrip, stripline, and grounded coplanar-waveguide (GCPW) transmission lines. Equations have been developed to calculate the amount of expected crosstalk from closely spaced parallel transmission lines, depending on factors like the distance between the transmission lines, the width of the transmission lines, and the permittivity (relative dielectric constant) of the printed-circuit-board (PCB) material.

Crosstalk, which is essentially noise, can occur in either direction in a circuit. When close to the source of the noise (e.g., LO leakage) it's often referred to near-end crosstalk, and when detected further from the source, it's called far-end crosstalk.

MICROSTRIP

With top-side conductors and bottom-side ground plane with dielectric material between the two, microstrip behaves most like an antenna when closely spaced transmission lines run in parallel (*Fig. 1*). The microstrip transmission line shown is fabricated on 20-mil-thick RO4003C PCB material from Rogers Corp. (www.rogerscorp.com). It's a hydrocarbon

ceramic laminate material with typical value of dielectric constant of 3.38 at 10 GHz, held to a tolerance of ± 0.05 .

Ideally, impedances in microstrip circuits can be closely matched to avoid mismatches and junctions susceptible to ringing and resonances that can boost crosstalk. Tight control of dielectric constant in a PCB material makes this possible.

In addition, proper ground-plane management and generous spacing between parallel transmission lines can help minimize conditions for crosstalk. For example, any reduction in ground-plane inductance will increase isolation and reduce crosstalk. Even the choice of coaxial connectors can have an impact the crosstalk levels of a high-frequency analog or high-speed digital circuit.

STRIPLINE

With transmission lines surrounded by dielectric material, stripline is less susceptible to crosstalk for two parallel transmission lines with the same spacing between them and the same width of transmission line. In stripline, high-frequency or high-speed signals are contained entirely within the PCB and the top and bottom conductive ground planes (Fig. 2). This minimizes emissions, and provides a good amount of shielding against incoming spurious signals.

A number of factors contribute to the amount of crosstalk produced in stripline circuits. These include the permittivity or relative dielectric constant of the circuit-board material, the height of the PCB's dielectric material, the length of the section of closely spaced parallel transmission lines, the height of each transmission line, and the spacing between the two transmission lines.

GCPW TRANSMISSION LINES

Thanks to their top-mounted transmission-line conductor on a PCB, surrounded on either side by ground planes, GCPW transmission lines (Fig. 3) achieve high isolation from coupled noise and thus minimize crosstalk. The GCPW's effective dielectric constant becomes equivalent to the combination of the permittivity of the dielectric PCB material on which the circuit traces are mounted, and the permittivity of air (unity) that surrounds the conductive traces and the ground planes. Microstrip and stripline circuits are somewhat more susceptible to crosstalk than GCPW circuits because of their generous grounding.

In general, any close placement of circuit traces that run parallel on a dielectric substrate will create a circuit structure that's essentially a capacitor. This section of the circuit will be capable of capacitive coupling and crosstalk, depending on the permittivity of the dielectric material. A number of other factors, including substrate dielectric loss, conductor loss, line thickness, and transmission-line width will contribute to the amount of crosstalk that occurs for a particular PCB.

IT'S A MATTER OF SPACE

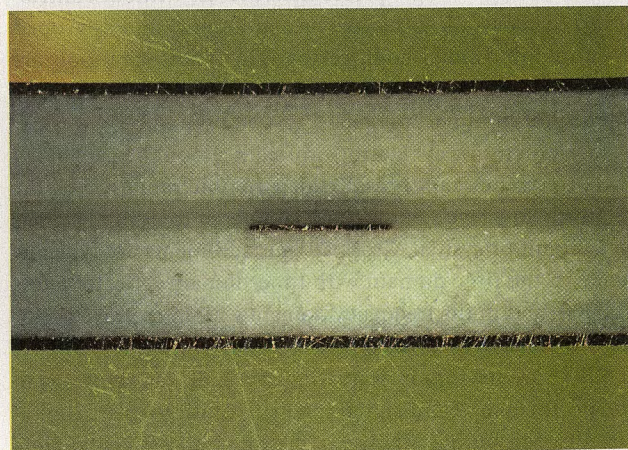
For single-layer, high-frequency analog and high-speed digital circuits, the areas of greatest concern are where transmission lines run in parallel. On multilayer circuits, areas of concern are where transmission lines from different circuit layers cross one another. In both cases, the close spacing of the transmission lines separated by the PCB's dielectric material forms a parasitic capacitor that's subject to coupling effects and crosstalk.

Current is coupled from the transmission lines with the intended signals to the nearby transmission lines. It's then transmitted through the parasitic capacitance between the two transmission lines. Depending on the impedances of the different transmission lines, the coupled current can result in voltage spikes that may degrade performance in analog circuits and disrupt operation in digital circuits.

In multilayer circuits, the use of grounded viaholes can also help minimize crosstalk. For effective shielding, the grounded viaholes must be placed closer together as the circuit's operating frequency climbs upward. In addition, differential circuit topologies are often used to achieve increased immunity to crosstalk.

Since high-speed digital signals exhibit the characteristics of high-frequency analog signals in terms of propagation and conduction, crosstalk is a concern for designers of high-frequency analog and high-speed digital circuits, and especially for designers of circuits containing both types of signals.

Although increasing the spacing between parallel transmission lines or the distance between lines that cross over each other in multilayer circuits can thwart attempts to miniaturize a PCB, it helps reduce or minimize crosstalk. Decreasing the length of a section of closely spaced parallel



2. The embedded conductor configuration of stripline, even with closely spaced parallel transmission lines, provides some shielding from crosstalk. This circuit from Rogers Corp. is formed with 20-mil-thick RO3003 laminate and 2929 bondply material (Courtesy of Rogers Corp.)

transmission lines can also help to shrink crosstalk for that portion of circuitry, since the amplitude of the crosstalk tends to rise with the increased length of the parallel transmission-line section.

In addition, using a low-impedance guard transmission line or circuit trace between two parallel transmission lines will work to reduce crosstalk. No doubt, separating analog and digital functions on a single-layer PCB is one of the simplest methods for minimizing crosstalk, although it may mean a less-than-efficient use of PCB area, too.

Power-supply circuitry is also susceptible to crosstalk from signal sources like LOs and clock oscillators. Under worst-case conditions, power-supply circuitry can conduct fundamental and harmonic signals from an oscillator throughout a circuit, with leakage signals added to the inputs of any amplifiers in the circuit to increase amplitude. Utilizing a decoupling capacitor in a circuit's power-supply filtering will help cut down the occurrence of crosstalk through the power-supply lines.

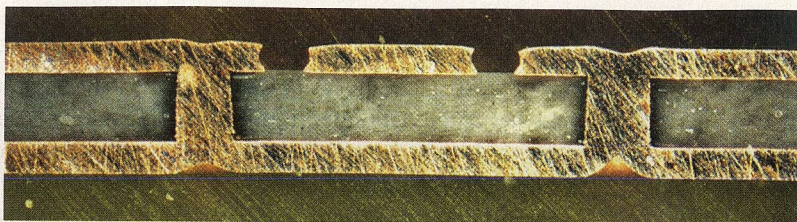
MEASURING CROSSTALK

The effects of crosstalk can be obvious in a communications system, such as loss of service or degraded system performance. Crosstalk is often difficult if not impossible to measure within packaged components and ICs, and removing the package changes the effective operating environment for the circuitry.

Of course, at the design stage, key goals are to create circuit structures and configurations that are the most rugged against crosstalk, and to choose PCB materials that best support the design's target performance levels without contributing to crosstalk. Effective measurements and appropriate computer-aided-engineering (CAE) software tools are essential in the design and characterization of RF/microwave circuits for minimal crosstalk.

Equipment for evaluating crosstalk should be capable of wide frequency ranges and wide dynamic range, given the relatively low levels of crosstalk compared to desired signals in a circuit or system. Crosstalk measurements are typically made in the time domain with time-domain reflectometers (TDRs), and in the frequency domain with microwave vector network analyzers (VNAs).

TDRs are useful for evaluating crosstalk as it pertains to the performance and signal integrity of high-speed digital circuits. Microwave VNAs can provide impressive dynamic range (of typically 80 dB or more) and are able to quickly measure and analyze forward and reverse signal transmission and reflection data without changing measurement setups. High-performance microwave VNAs that can accurately



3. This GCPW from Rogers Corp. was fabricated on RT/duroid{R} 5880 laminate. It shows the ground planes on either side of the signal conductor, which provides good isolation from crosstalk. (Courtesy of Rogers Corp.)

measure crosstalk are available from a number of companies, including Anritsu Co. (www.anritsu.com), Keysight Technologies (www.keysight.com), and Rohde & Schwarz (www.rohde-schwarz.us).

In the digital realm, crosstalk is often measured with the aid of bit-error-rate (BER) testers. That's because excessive crosstalk has been found to compromise the BER performance of high-speed digital circuits. By generating test signals that closely emulate the actual signals to be carried by the circuits under test, such as with an arbitrary waveform generator, it's possible to examine crosstalk's impact on the signal integrity (SI) of a high-speed digital circuit's SI. It compares the difference between circuit operation with and without input signals (and with and without crosstalk).

In addition to characterizing a circuit design through wide-dynamic-range measurements, CAE software tools such as electromagnetic (EM) simulation software can save time when exploring potential crosstalk issues that may crop up in a circuit design.

Tools like the Sonnet Suites from Sonnet Software (www.sonnetsoftware.com) make it possible to predict the EM behavior of different circuit configurations and types of transmission lines, including the effects of PCB materials. In fact, Sonnet offers SonnetLite as a free download from its website, as a form of risk-free introduction to the use of a 3D EM simulation tool.

Additional suppliers of high-quality EM simulation tools include Computer Simulation Technology (CST, www.emsimulation.com), Keysight Technologies (www.keysight.com), National Instruments (www.ni.com), and Remcom (www.remcom.com) (see *Microwaves & RF*, September 2015, p. 42, for more details on EM simulators).

These measurement and simulation tools can help monitor and minimize crosstalk for a wide range of circuit architectures and substrate materials. Essentially, what's important to know isn't so much the level of crosstalk, but the effects it has on a circuit's performance and essential functions. Through careful circuit design and spacing of any parallel transmission lines, crosstalk can usually be held in check, even at the highest frequencies and fastest digital speeds. **mw**

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- Pulse modulation
- USB control



2U 19" Rack-Mount Option Available



Software Innovates RF/Microwave Test Environments

Software is available from a range of vendors in a variety of forms, providing advanced test capabilities that include everything from real-time spectrum analysis to signal creation and more.

ADVANCED TEST SYSTEMS are necessary to meet today's challenging time-to-market and performance requirements. As devices grow in complexity, software is proving to be an extremely vital aspect of RF/microwave testing. Sophisticated software tools are available to increase the efficiency of test environments. Automated test engineers, who need to develop innovative systems, can use these tools to develop solutions capable of meeting today's demands. Various types of software intended to simplify the testing process are currently available.

To meet current demands, for example, engineers continue to use LabVIEW from National Instruments (NI) to develop test software solutions (Fig. 1). LabVIEW can be integrated with a variety of test instrumentation, ranging from traditional boxes to modular PXI-based hardware. The latest version of the software, LabVIEW 2015, offers several new features.

"LabVIEW 2015 includes several new enhancements that enable users to write code faster and write faster code," says Haydn Nelson, senior product manager at NI. "These improvements include changes to the LabVIEW compiler itself along with new driver software like NI-RFmx. In the LabVIEW application development environment, NI has made improvements to load times, execution speed, and memory usage. Because RF measurements tend to be computationally intensive, each of these new enhancements in LabVIEW 2015 has ultimately improved test speeds in automated test applications."

Nelson adds, "NI-RFmx is an application programming

interface (API) designed specifically with LabVIEW and the PXI platform in mind. It provides an intuitive programming measurement experience combined with advanced features

for measurement parallelism. NI-RFmx

has the capability to allow users to easily decouple RF signal-acquisition from measurement analysis. This is accomplished by means of an API that enables the instrument to acquire measurement data and perform analysis in parallel when conducting multiple measurements.

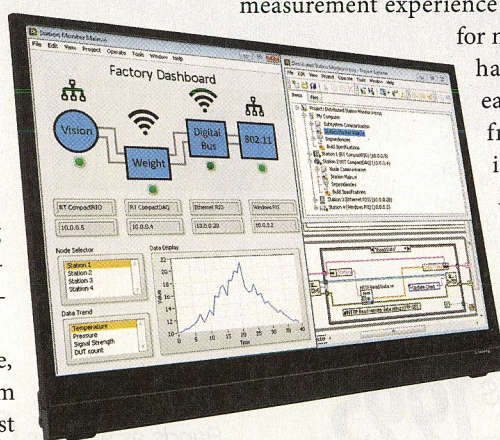
Known as an asynchronous measurement, this had been difficult or even impossible to achieve with traditional instruments. But NI-RFmx makes asynchronous measurement parallelism possible. Asynchronous measurement parallelism takes advantage of multicore central processing unit

(CPU) technology, enabling engineers to improve overall automated test speed—sometimes by an order of magnitude."

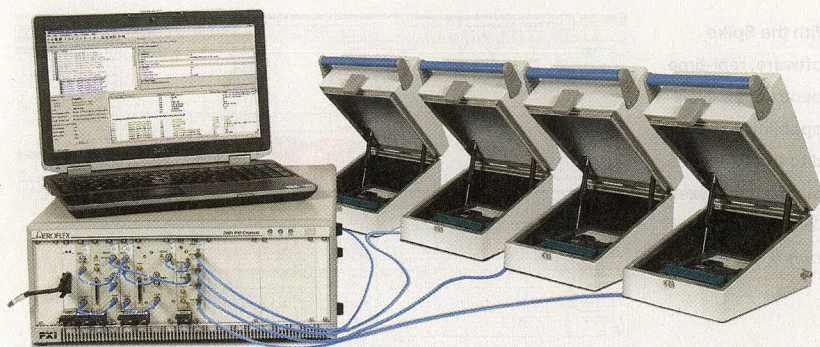
SOFTWARE SOLUTIONS FOR WIRELESS TEST

Test software is an important aspect of automated test systems for wireless applications. As devices become more complex, delivering quality products to market in a timely fashion is even more challenging. Thus, test software is critical for both device characterization and high-volume production requirements. Fortunately, solutions are available to meet these demands.

As an example, LitePoint offers the IQfact+ calibration and verification software solution for wireless chipsets. IQfact+ sup-



1. LabVIEW 2015 provides performance benefits, such as improved load times, execution speed, and memory usage. (Courtesy of National Instruments)



2. The PXI Maestro test software allows a single RF channel to test multiple devices. (Courtesy of Cobham Wireless)

ports wireless connectivity technologies, such as Wi-Fi, Bluetooth, ZigBee, Global Positioning System (GPS), near-field communications (NFC), and more. Its library includes more than 300 chipsets.

To facilitate test synchronization, IQfact+ controls both the LitePoint tester and the device-under-test (DUT). Chipset calibration algorithms are also provided by the software. The company claims it can enable test systems to be deployed in hours compared to a development time of weeks or even months for traditional test automation systems.

To support the demands of 4G LTE cellular standards, LitePoint offers the zSignal LTE software toolkit. Intended for compliance testing and characterization of LTE cellular devices, this test solution provides demodulation and vector signal analysis capabilities. Users are provided with the tools needed to generate and analyze LTE RF and baseband I/Q signals. Similarly, LitePoint's zSignal WLAN software supports wireless-local-area-network (WLAN) applications.

Digital pre-distortion (DPD) techniques are being employed in many of the latest WLAN transceiver chipsets to improve power amplifier (PA) linearity. In response, LitePoint offers the zSignal DPD software, which is a DPD software toolkit for PA and front-end module (FEM) characterization and testing. This software has the capability to measure the nonlinearity of a PA, compute an inverse operation, and then create a pre-distorted RF signal that effectively linearizes the

PA. When combined with the zSignal WLAN software, zSignal DPD supports PA/FEM DPD testing for IEEE 802.11 WLAN devices. Similarly, zSignal DPD supports PA/FEM DPD testing for LTE cellular devices when combined with the zSignal LTE software toolkit.

Heterogeneous Networks (HetNets) incorporate different varieties of small-cells. To support these networks, the PXI Maestro test system from Cobham Wireless was recently enhanced with the introduction of small-cell test capability (Fig. 2). The company's ATE system is based on PXI modular instruments and the PXI Maestro test sequencing software. This introduction provides integrated device control software for Qualcomm Technologies' FSM99xx based multi-mode enterprise, residential, and metro small cells.

The PXI Maestro test software integrates all the sequencing control needed to measure multiple DUTs. Users can test as many as four small cells in parallel with a single RF channel—a single vector signal analyzer and signal generator—by means of novel RF signal conditioning and intelligent test sequencing. The PXI Maestro small cell capability provides frequency coverage to 6 GHz for all LTE, LTE-A, and High Speed Packet Access (HSPA) bands.

MANUFACTURERS INTEGRATE HARDWARE WITH SOFTWARE

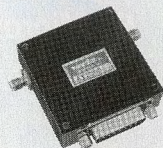
Many companies regarded as test equipment suppliers are also developing

PIN DIODE CONTROL DEVICES

PIN DIODE

ATTENUATORS

- 0.1–20GHz
- Broad & narrow band models
- Wide dynamic range
- Custom designs

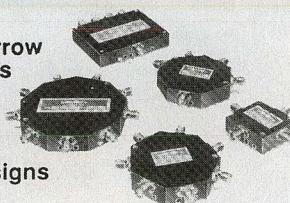


Attenuator types offered are: Current Controlled, Voltage Controlled, Linearized Voltage Controlled, Digitally Controlled and Digital Diode Attenuators.

PIN DIODE

SWITCHES

- Broad & narrow band models
- 0.1–20GHz
- Small size
- Custom designs

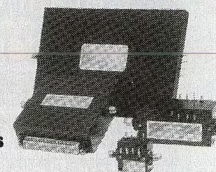


SPST thru SP8T and Transfer type models are offered and all switches are low loss with isolation up to 100dB. Reflective and non-reflective models are available along with TTL compatible logic inputs. Switching speeds are 1μsec.—30nsec. and SMA connectors are standard. Custom designs including special logic inputs, voltages, connectors and package styles are available. All switches meet MIL-E-5400

PIN DIODE

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- Varactor Controlled
- Vector Modulators
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- QPSK Modulators
- Custom Designs



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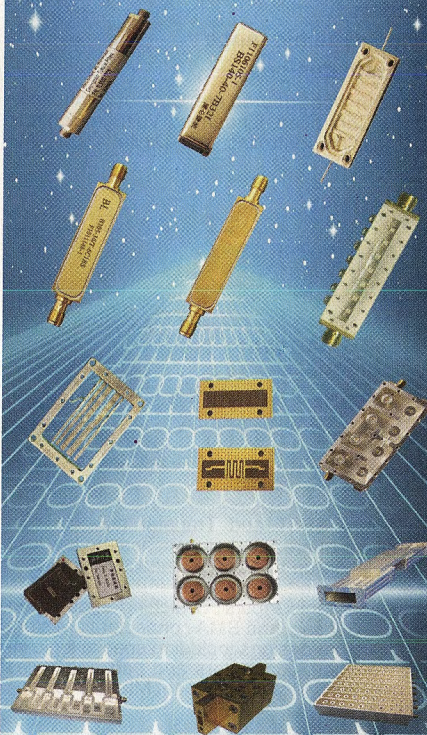
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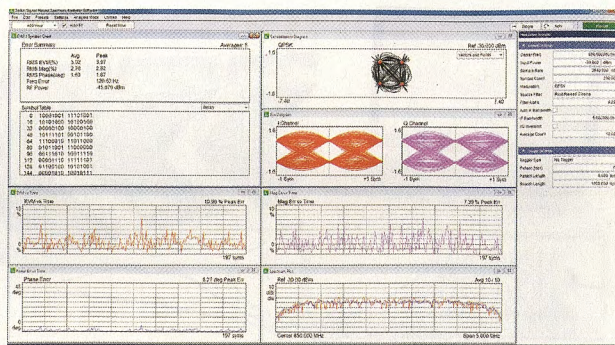
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Industry Trends

With the Spike
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their own custom software. The integration of hardware and software is intended to help users streamline the testing process. Many improvements to the test workflow can now be achieved by means of a more integrated approach. One improvement is combined functionality, as software is being used to enhance traditional instrument measurement capability.

For example, the SignalVu vector signal analysis software from Tektronix integrates the test process by combining the functionality of vector signal analyzers and spectrum analyzers with the trigger capabilities of digital oscilloscopes. The software, which is intended to be used with an MSO/DPO5000, DPO7000, or DPO/DSA/MSO70000-series digital oscilloscope, enables users to directly observe microwave signals without needing an external down-converter. All signals within the analog bandwidth of the oscilloscope can be captured into memory. RF, I/Q, and differential I/Q signals can be processed from any of the four oscilloscope inputs. SignalVu is intended to help validate designs for applications, such as wide-band radar, high-data-rate satellite links, WLAN, and frequency-hopping communications.

For its part, Signal Hound is another company that has developed its own software (Fig. 3). The software, which is named Spike, provides performance enhancements to several of the company's products. It allows all the SA-series spectrum analyzers and TG-series tracking generators to operate under the same

open source GUI platform as the BB60C spectrum analyzer.

Spike, which is available free of charge, allows the SA-series models to function as real-time spectrum analyzers for 250-kHz sweeps and below. This functionality enables every RF event to be captured when using a span within 250 kHz. The software also enables sweep speeds to be as much as 8 times faster when using spans between 500 kHz and 2 MHz. Additionally, the tracking generators can now save 1000-point data files that can be used to normalize precise measurements with RF cables and/or antennas.

The Spike software was recently updated with the introduction of version 3.0.8. This version introduces real-time digital modulation analysis tools for the BB60C and BB60A spectrum analyzers. Constellation diagrams, symbol tables, error vector magnitude (EVM) measurement capability, and bit pattern matching analysis tools for a wide range of modulation types are provided. When used with a BB60C or BB60A, the updated software includes real-time tools to analyze digitally modulated signals with bandwidths to 27 MHz at frequencies from 9 kHz to 6 GHz.

With its Amplifier Test Bench software, Boonton (which is part of the Wireless Telecom Group) aims to provide an integrated approach to RF amplifier testing. This integration allows users to perform measurements with just a few mouse clicks. Advanced programming skills are not required, thus simplifying the user experience. The software enables automatic testing of RF ampli-



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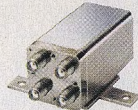
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fier parameters, among other features. Amplifier Test Bench, which supports both high-power and small-signal amplifiers, is intended to be used with the company's 4540 and 4500B power meters. It also supports a variety of signal/pulse generators.

Amplifier Test Bench supports measurements like gain over frequency, gain over input power, and voltage-standing-wave-ratio (VSWR) over frequency. It can also plot power versus frequency responses with one or multiple traces on the display. In addition, the software provides the capability to measure input and output power simultaneously.

By providing the IMDView software, Anritsu is integrating intermodulation distortion (IMD) measurement capability into its VectorStar vector network analyzers (VNAs). The software provides a GUI to simplify complex IMD measurements. IMD-View also offers the capability to modify tone parameters while viewing the results in real-time, enabling engineers to quickly determine optimum performance capabilities.

Rohde & Schwarz offers a number of software products designed to be used with many of its test instruments, such as signal generators, spectrum analyzers, and oscilloscopes. Software is provided for both signal generation and signal analysis. One example is the WinIQSIM2 simulation software, which allows users to generate digitally modulated signals. The software can be used with the AFQ100A and AFQ100B arbitrary waveform generators as well as various signal generators.

SIGNAL CREATION SOFTWARE

With its Signal Studio software, Keysight Technologies provides users with a suite of tools to create test signals for specific applications. Both baseband and RF/microwave signals can be created with the software, which is intended to reduce the amount of time required for signal simulation. Users have the option to select from available presets or create their own custom reference signals. These signals can be used to test

devices intended for applications like cellular communications, wireless connectivity, and digital broadcast standards. Test patterns can be defined for advanced wireless systems used for detection, positioning, tracking, and navigation. Once signals are fully defined, they can be downloaded to various Keysight test instrumentation and design software.

New additions were recently introduced to the Signal Studio suite of products. One of the latest releases is the N7608B Signal Studio for Custom Modulation software. Released earlier this year, this software aims to support 5G in its early stages by providing the capability to create custom waveforms for 5G applications. Waveform candidates for 5G, such as custom filter bank multi-carrier (FBMC), OFDM, and I/Q signals, can be generated with the N7608B software.

Another recent introduction is the N7605B Signal Studio for Real-Time Fading software. With this software, wireless communication systems can be evaluated by predicting their performance in response to real-world conditions. When used jointly with an N5172B EXG or N5182B MXG vector signal generator (VSG), the software can apply fading to digital baseband signals. In addition, additive-white-Gaussian-noise (AWGN) can be applied. The faded and noisy signals can then be converted to RF frequencies. Preconfigured fading profiles are available to simplify initial setups, or user-defined fading profiles can be chosen to meet specific test needs. The software supports various fading types, such as Rayleigh, Rician, log-normal, Suzuki, and pure Doppler.

Various software products are available to meet today's RF/microwave test requirements. Vendors have developed clever techniques to streamline test systems. Many different options provide solutions to the testing needs of a wide range of applications. Clearly, software is playing an important role in the realm of test. With the vast array of offerings, companies can choose the test solutions that best fit their specific needs. **mw**



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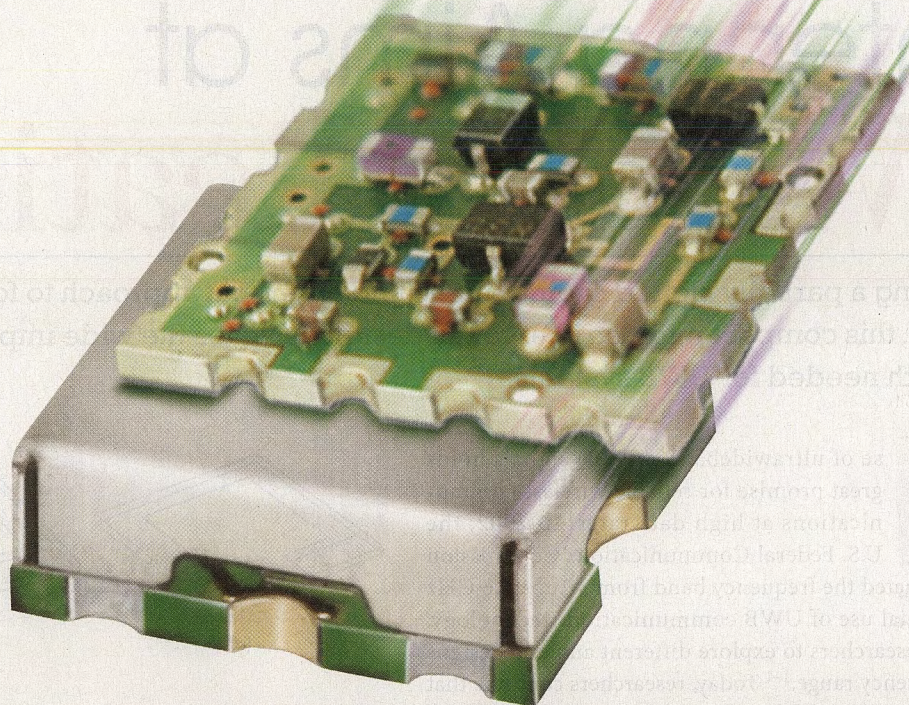
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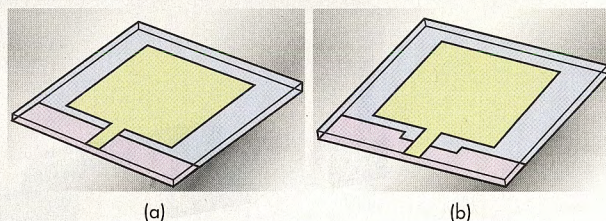
Novel Microstrip Antenna Aims at UWB Applications

By enlisting a partially slotted ground plane and a step-cut approach to forming radiating elements, this compact microstrip antenna design achieves the wide impedance bandwidth needed for UWB systems.

Use of ultrawideband (UWB) signals holds great promise for reliable wireless communications at high data rates. In 2002, the U.S. Federal Communications Commission (FCC) designated the frequency band from 3.1 to 10.6 GHz for commercial use of UWB communications technology, prompting researchers to explore different antenna designs for that frequency range.¹⁻⁴ Today, researchers continue that pursuit, recently developing a compact monopole antenna with a single-slotted ground plane and stepped rectangular resonator structure. It measures just $20 \times 15 \text{ mm}^2$ and achieves a voltage standing wave ratio (VSWR) of less than 2.00:1 from 2.65 to 10.00 GHz.

Successful implementation of these UWB wireless-communications systems depends on effective and compact antennas with near omnidirectional radiation patterns. Such antennas are also required for radar, medical imaging, and radio-frequency-identification (RFID) applications, in support of high data rates at low power levels.⁵

Printed monopole antennas have received lots of attention in recent years for their simple topologies, wide impedance bandwidths, low cost, omnidirectional radiation patterns, and relative ease of fabrication. Simple feed structures also make these antennas attractive for use in wireless-communications integrated-circuit (IC) technology. Different structures and approaches have been employed to fabricate these antennas, with varying degrees of success.^{6,7} The candidate antenna, designed for a broad bandwidth, is a printed planar monopole design.

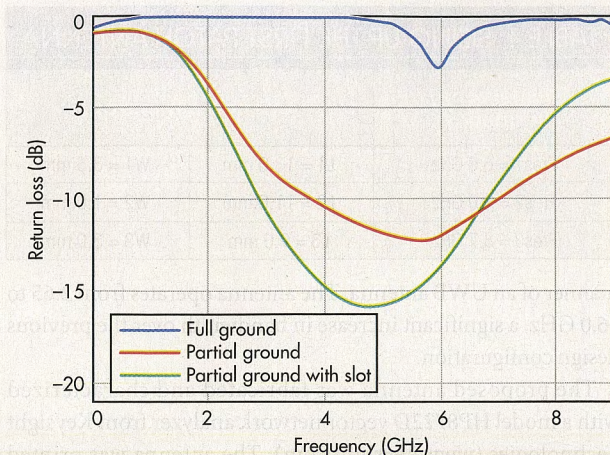


1. These patch antenna designs feature modified ground structures: (a) with a partial ground and (b) with a partial ground and etched slot.

Printed microstrip slot antennas have seen wide use in commercial and military wireless applications.⁸⁻¹⁰ They offer many benefits, including compact size, light weight, ease of implementation, and low cost, and can be easily integrated with microwave circuits. The most common antenna topology is a rectangular and circular patch.

REFINING THE MICROSTRIP

Of course, microstrip patch antennas also suffer some disadvantages, including low gain and low impedance bandwidth. Several techniques have been applied to overcome these limitations, emphasizing large bandwidth and small size. In one, an antenna with a meandering form achieved improved gain through a genetic algorithm.¹¹ Another design employed a Hilbert curve fractal for RFID applications.^{12,13} A third approach relied on high-permittivity dielectric substrate material to minimize printed antenna size.¹⁴ Unfortunately, this material increases the flow of surface waves and reduces antenna gain.



2. These plots show return-loss performance for different antenna ground shapes.

A number of different UWB antennas have been realized for applications from 3.1 to 10.6 GHz, including an ring antenna,¹⁵ a spline-shaped antenna,¹⁶ triangular patch antennas,¹⁷ and square printed antennas using a defected microstrip structure (DMS) with different topologies printed on substrates.

Some researchers investigated microstrip antennas combined with defected-ground-structure (DGS) technology, which is incorporated in the ground plane or with a DMS slot etched in the radiating patch. Such antennas consist of radiating structures spaced a small fraction of a wavelength above a ground plane and directly connected using an input port through a planar feed.

These various studies on UWB antennas led to improved antenna impedance bandwidths. Efforts to etch a DGS on the ground plane or a DMS on the radiating patch were used to improve the impedance bandwidth and radiation characteristics. Numerous DMS-DGS shapes with different topologies, such as an open-loop ring slot,¹⁸ a U-shaped slot,¹⁹ and a square-ring slot²⁰ have been investigated. Other researchers have used the tunable features of different shapes to significantly increase slot antenna bandwidth, achieving wide tuning ranges for different shapes, including H-shaped,²¹ L-shaped,²² and C-shaped tuning-stub configurations.²³

“STEPS” TOWARD IMPROVEMENT

These different efforts to cover wide bandwidths in small antenna configurations show that improvements in size and radiation properties were obtained by cutting “stair steps” into each radiating element and using an etched slot in the partial ground plane. Because such a quasi-fractal technique does not provide a sufficiently large bandwidth, a notch was inserted in the partial ground plane with the goal of increasing the antenna bandwidth.

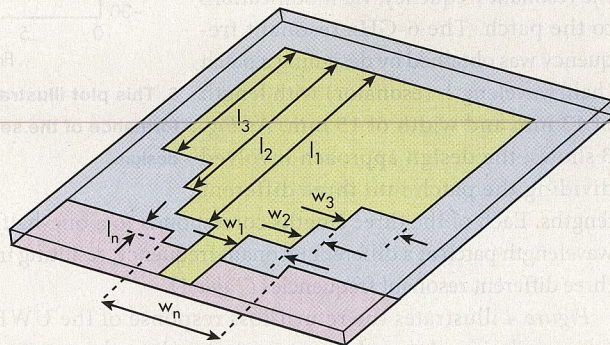
Antenna design and optimization were performed with the aid of circuit simulations using computer-aided-engineering

(CAE) design software from AWR Corp. (www.awrcorp.com) and Computer Simulation Technology (www.cst.com). The simulation software allowed for analysis of antenna radiation patterns and performance, including VSWR and return loss.

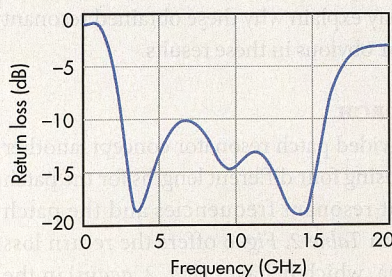
Figure 1 shows the three-dimensional (3D) layout of the designed patch antenna with its modified ground plane. The rectangular monopole antenna was printed on RO4003 circuit laminate from Rogers Corp. (www.rogerscorp.com), which has relative permittivity of 3.38 at 10 GHz in the z-direction (thickness) of the material. The circuit laminate had thickness (h) of 0.813 mm and exhibits a dielectric loss tangent of 0.00027 at 10 GHz.

To achieve wideband performance, multiple adjacent resonant frequencies should be created to obtain the desired response by driving the return loss below -10 dB within the desired frequency range. Reaching this goal required several parametric studies on the ground and patch. The fringing fields were created at resonant frequencies between the patch edges and the ground metal.

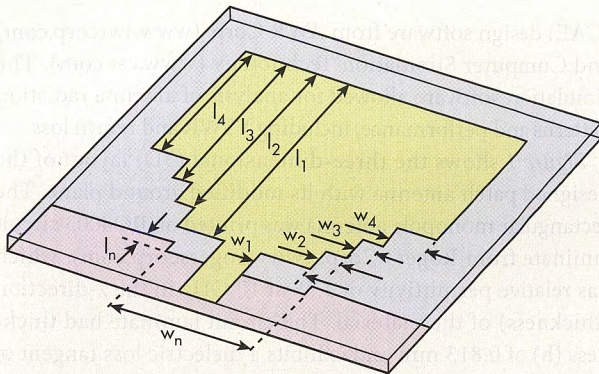
One approach to improve return loss involved widening the fringing fields by increasing total radiation; this was done by changing the ground's dimensions to cover the area below the feed line while preserving its total width (Fig. 1a). In such a configuration, the fringing fields from the patch edges will try to reach the ground plane. This will enable the antenna to radiate around the resonant frequency. To improve the broadband impedance matching, a simple U-shaped slot was etched from the ground (Fig. 1b) with a width of 7 mm and length of 1 mm.



3. Shown here is a three-dimensional (3D) view of a wideband patch antenna.



4. Return loss of the wideband patch antenna return in Fig. 3 is better than 10 dB from 2.45 to 15.8 GHz.



5. Key dimensions are provided in this 3D view of the second wideband antenna design.

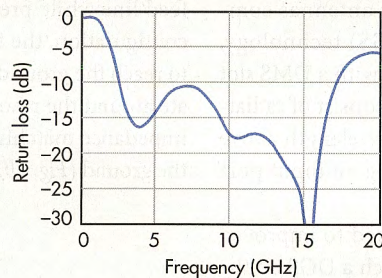
Figure 2 compares antenna return losses for different ground shapes, including an ordinary rectangular (full) ground structure that fully covers the circuit substrate and smaller structures with partial ground and partial ground with additional slot. The antenna with full ground structure had a resonance at 6 GHz and exhibited the smallest bandwidth of the antenna shapes. Return loss improved significantly by using the partial ground—return loss at resonance dropped to -12.3 dB for a bandwidth of 4.0 to 6.5 GHz. The added slot dropped the return loss to -15.7 dB for a bandwidth of 3.5 to 6.5 GHz.

Its use in UWB applications required a significant increase in return loss around the resonant frequency, via modifications to the patch. The 6-GHz resonant frequency was obtained by designing a patch (half-wavelength resonator) with length of 13 mm and width of 15 mm. As Fig. 3 shows, the design approach involved dividing the patch into three different lengths. Each of the three lengths corresponds to a one-half-wavelength patch at a different resonant frequency, resulting in three different resonant frequencies (Table 1).

Figure 4 illustrates the return-loss response of the UWB antenna design. As can be seen from the plots, the antenna operates with return loss of better than 10 dB from 2.45 to 15.8 GHz, with total antenna bandwidth of 13.35 GHz. The width of each resonator is considered small compared to the width of a single resonator. This may explain why these obtained resonant frequencies didn't appear obvious in these results.

A DIFFERENT APPROACH

By using this same divided patch resonator concept, another antenna was simulated using four different lengths for the patch (Fig. 5). The equivalent resonant frequencies and the patch dimensions are shown in Table 2. Fig. 6 offers the return loss of the proposed antenna, which behaves (Fig. 2, again) in the



6. This plot illustrates the return-loss performance of the second wideband antenna design.

TABLE 1: SIZING UP THE FIRST PATCH ANTENNA

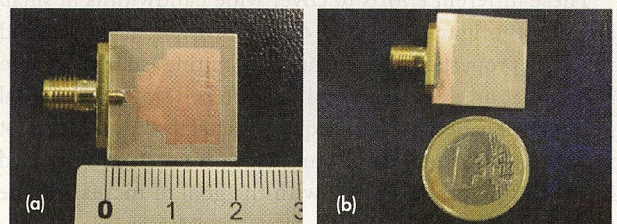
Fresnel zone/ frequency	Antenna dimensions	
Fres1 = 6.0 GHz	L1 = 13.0 mm	W1 = 3.5 mm
Fres2 = 7.0 GHz	L2 = 11.0 mm	W2 = 1.0 mm
Fres3 = 8.7 GHz	L3 = 9.0 mm	W3 = 3.0 mm

manner of an UWB antenna. The antenna operates from 2.65 to 16.0 GHz, a significant increase in bandwidth over the previous design configuration.

The proposed antenna was fabricated and characterized with a model HP8722D vector network analyzer from Keysight Technologies (www.keysight.com). The antenna was printed on RO4003 circuit substrate material from Rogers Corp. with a relative dielectric constant (ϵ_r) of 3.38 and thickness (h) of 0.813 mm (Fig. 7).

Figures 8 and 9 show the antenna's measured return loss and VSWR, respectively. Inspecting the measurement results of Fig. 8, the experimental results demonstrate antenna operation from 4 GHz to more than 10 GHz with return loss of less than about 10 dB. Compared to simulated results, the experimental results agree closely. Some amount of frequency shift was observed between the simulated and measured results, which can be due to the imperfect full-wave simulation methods and lack of total fabrication accuracy and tolerance control.

To investigate the UWB antenna's behavior, surface-current distributions were studied at different frequency bands. The current distribution was calculated at two frequency bands—the first one at 1 GHz, considered below the operating frequency range, and at 10 GHz, considered the end of the antenna's frequency range. At 1 GHz, the antenna didn't radiate and all power is reflected. But at 10 GHz, the antenna radiates effectively. (For detailed computer simulation results of the proposed antenna, check out the online version of this article at www.mwrf.com.)



7. The photographs show the (a) top view and (b) bottom view of the fabricated wideband microstrip antenna with connectors for testing.



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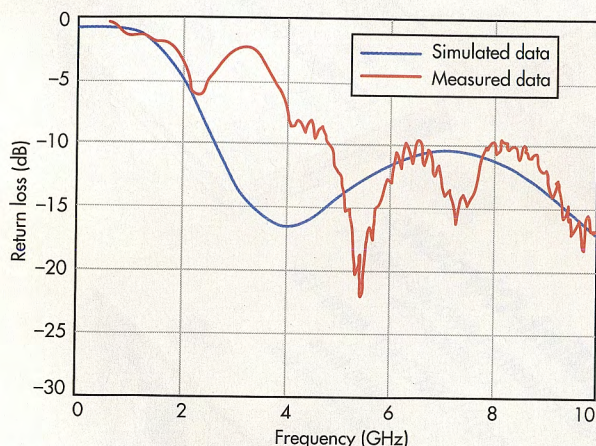
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RCDAT-6000-60	0-60 dB	±0.3 dB	0.25 dB	✓	✓	-	\$725
RUDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	-	✓	\$695
RCDAT-6000-90	0-90 dB	±0.4 dB	0.25 dB	✓	✓	-	\$795
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NEW RCDAT-6000-110	0-110 dB	±0.45 dB	0.25 dB	✓	✓	-	\$995
NEW RUDAT-4000-120	0-120 dB	±0.5 dB	0.25 dB	✓	-	✓	\$895
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8. These plots compare the measured and computer-simulated return loss of the novel patch antenna.

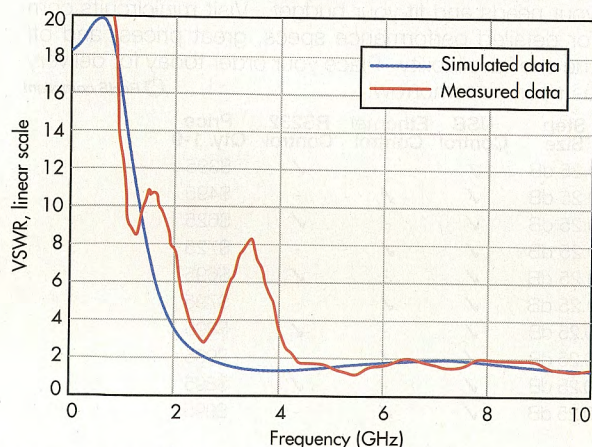
CONCLUSION

This compact monopole patch antenna achieves a wide impedance bandwidth of 116% with 10-dB return loss at a center frequency of 6.33 GHz. It features the broadband frequency coverage from 2.66 to 10.00 GHz for WLAN applications. By adding an etched rectangular slot in the ground plane, the antenna gains improved impedance matching and radiation characteristics. An edge-cut technique was employed to reduce antenna size and enhance bandwidth.

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9. These plots compare the measured and simulated VSWR behavior of the novel patch UWB antenna.

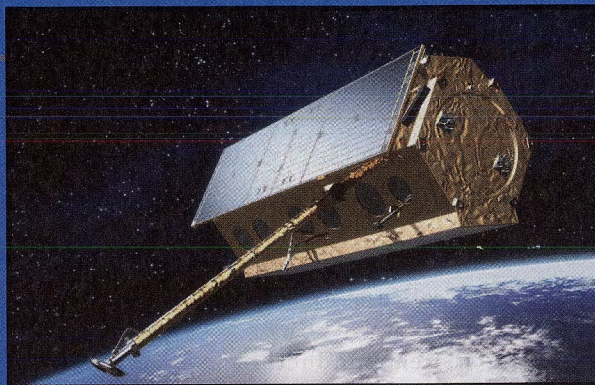
TABLE 2: SIZING UP THE SECOND PATCH ANTENNA

Fresnel zone / frequency	Antenna dimensions	
Fres1 = 6.0 GHz	L1 = 13.0 mm	W1 = 3.5 mm
Fres2 = 6.9 GHz	L2 = 11.5 mm	W2 = 1.0 mm
Fres3 = 7.9 GHz	L3 = 10.0 mm	W3 = 1.0 mm
Fres4 = 9.15 GHz	L4 = 8.5 mm	W4 = 2.0 mm

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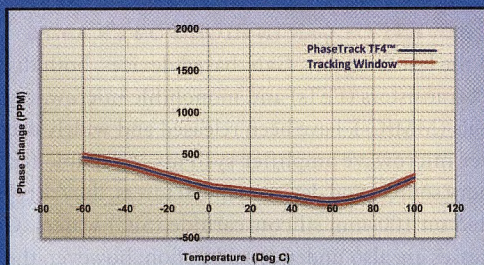


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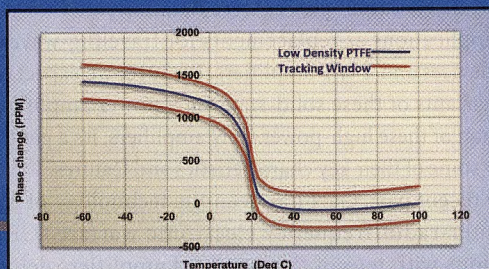
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What's the State of GaN Power Amplification?

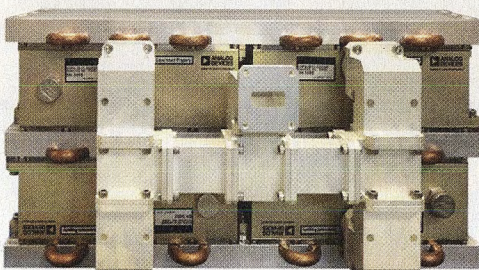
Improvements in GaN power semiconductor technology and modular design enable high-power CW and pulsed amplifiers at microwave frequencies.

Gallium-nitride (GaN) power semiconductor technology has helped significantly improve performance levels in RF/microwave power amplification. By reducing device parasitic elements and using shorter gate lengths, and using higher operating voltages, GaN transistors have reached higher output-power densities, wider bandwidths, and improved dc-to-RF efficiencies.

For example, by 2014, GaN-based X-band amplifiers capable of 8-kW pulsed output power were demonstrated for radar-system applications as replacements for traveling-wave-tube (TWT) devices and TWT amplifiers. By 2016, we expect to see 32-kW variants of these solid-state GaN power amplifiers. In anticipation of these high-power GaN amplifiers, it's a good time to review some of their key characteristics and features.

In the recent past, GaN has been the technology of choice for counter-radio-frequency electronic warfare (CREW) applications with tens of thousands of amplifiers delivered for field use. The technology is now being deployed in the airborne EW arena as well, with amplifiers under development able to deliver hundreds of watts of output power across multiple octaves in the RF/microwave range. Several variants of these wideband EW power amplifiers are due for release in the current calendar year.

Areas for further research include improvements in linearity for high peak-to-average-power-ratio (PAPR) waveforms employed in many military communications systems, including common data link (CDL), wideband network-



1. This GaN-based solid-state power amplifier is capable of 8-kW output power at X-band frequencies.

ing waveform (WNW), soldier radio waveform (SRW), and wide-band satellite-communications (satcom) applications. Along those lines, Analog Devices (www.analog.com) is pursuing the “Bits to RF” initiative, which integrates the company’s strengths in base-band signal-processing and GaN power-amplifier (PA) technologies. This integration will enable advances in PA linearity and effi-

ciency via techniques such as predistortion and envelope modulation.

THE ADVENT OF GaN IN HIGH-POWER AMPS

In the last few years, GaN-based devices, both discrete field effect transistors (FETs) and monolithic microwave integrated circuits (MMICs), have been released and widely used in high-power microwave amplifier systems. Available from several foundry sources and device manufacturers, they’re typically fabricated on 100-mm silicon-carbide (SiC) wafers. GaN-on-Si processes are also under consideration; however, the relatively poor thermal and electrical conductivities of Si offsets the cost advantages in high-performance, high-reliability applications.

GaN-based devices feature gate lengths as small as 0.2 μm and support operation into millimeter-wave frequency bands. Such devices have largely replaced gallium arsenide (GaAs) and Si laterally diffused metal-oxide-semiconductor (LDMOS) devices in high-frequency applications and all but the most cost-sensitive, lower-frequency applications.

RF power-amplifier designers are attracted to GaN devices because they support very high operating voltages (three to

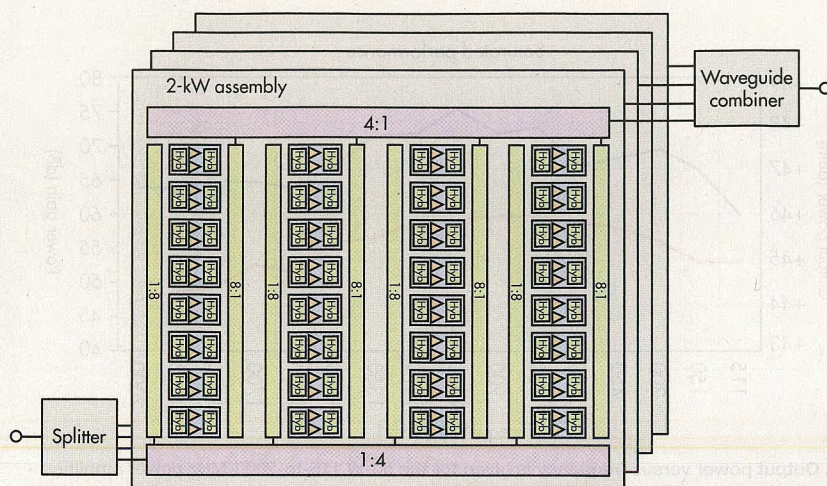
five times higher than those of GaAs), and roughly double the allowable current per unit FET gate width compared to GaAs devices. These characteristics have an important consequence to PA designers, specifically a higher load impedance for a given output power level.

Previous GaAs- or LDMOS-based designs often had extremely low output impedances relative to typical system impedances of 50 or 75 Ω . Low device impedances place limits on achievable bandwidth. In other words, as the required impedance transformation ratio between the amplifying device and its load increases, the number of components and insertion loss increase as well. Due to these high impedances, early users of these devices sometimes were able to achieve partial results by merely installing one in an unmatched test fixture, applying dc bias, and driving the device with an RF/microwave test signal.

GaN devices are also finding their way into high-reliability space applications due to these operating characteristics and their exceptional reliability. Life test data from several sources of these devices predict mean-time-to-failure (MTTF) durations (for single devices) in excess of 1 million hours at junction temperatures of 225°C or higher. This exceptional reliability is mainly due to the high bandgap value for GaN (3.4 for GaN vs. 1.4 for GaAs). This makes them more than suitable for high-reliability applications.

COST IMPLICATIONS

The chief impediment to wider use of GaN in high-power applications has been its relatively high fabrication costs—

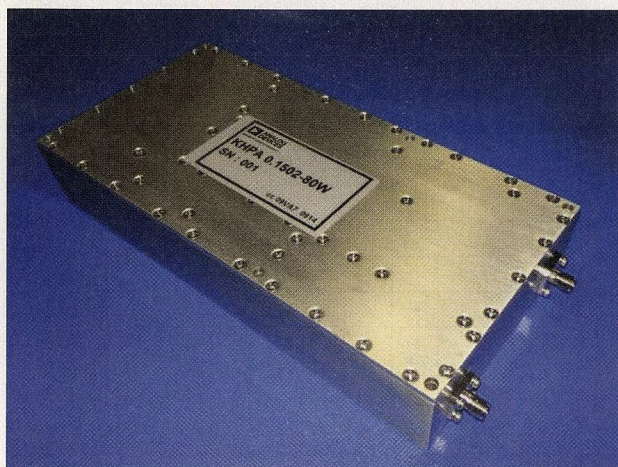


2. This block diagram represents the structure and components of the GaN X-band solid-state power amplifier.

typically two to three times that of GaAs and five to seven times that of Si LDMOS-based devices. It's become a barrier for cost-sensitive applications such as wireless infrastructure and consumer handsets.

GaN-on-Si-substrate processes are available, albeit with the performance issues noted earlier. Nonetheless, devices from these processes are probably best suited for these cost-sensitive applications. In the near future, cost reductions, perhaps on the order of 50%, are expected as GaN-device fabrication moves to larger wafers—several leading foundries in this realm are now developing wafers with diameters of 150 mm and larger.

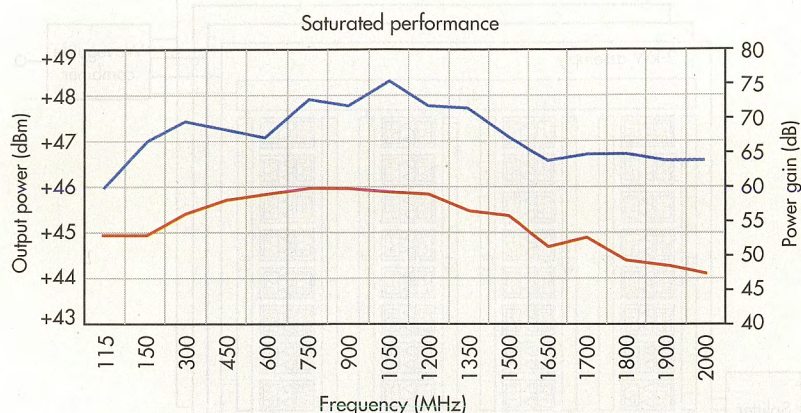
Currently deployed radar systems for weather prediction and target acquisition/identification rely on TWT-based power amplifiers operating at C- and X-band frequencies. The amplifiers run at high supply voltages (10 to 100 kV) and temperatures, and are susceptible to damage from excessive shock



3. This continuous-wave (CW) 50-W solid-state power amplifier operates from 115 to 2000 MHz.

TABLE 1: TYPICAL 8-kW PA PERFORMANCE

Rated output power	8 kW
Frequency range	8 to 11 GHz
Rise/fall time (max.)	200 ns
Pulse width	0.05 to 100 μ s
Duty cycle	20%
Input/output VSWR	1.50:1
Out-of-band spurious noise (max.)	-70.0 dBc
Second harmonics (max.)	-40.0 dBc
RF input connector	SMA
RF output connector	Waveguide



4. Output power versus frequency is given for the 50-W 115-to-2000-MHz power amplifier.

and vibration. The reliability in the field for these tube-based amplifiers is typically 1200 to 1500 h, which leads to high costs for maintenance and spare parts.

GaN-BASED OPTION TO TWT AMPS

As an alternative to these high-power TWT-based amplifiers, Analog Devices developed an 8-kW, solid-state, X-band power amplifier based on GaN technology. The design uses an innovative, layered combiner approach to sum the contributed RF/microwave output power of 256 MMICs, each developing approximately 10-W output power. The combining methodology results in graceful performance degradation in the event of individual MMIC failures.

Conversely, TWT amplifiers tend to suffer catastrophic-type failures due to low levels of redundancy. For these GaN solid-state power amplifiers (SSPAs), the RF/microwave combining architecture must present a reasonable balance between the isolation required between MMICs and the RF/microwave insertion loss of the overall network.

The 8-kW amplifier topology is modular; it combines the output power of four 2-kW amplifier assemblies using waveguide structures (Fig. 1). The amplifier can be mounted in a standard 19-in. rack enclosure. The amplifier's design is configured for water cooling (Fig. 2), although variants of the amplifier using air cooling are under development. Table 1 summarizes the performance levels for the water-cooled 8-kW GaN PA.

Due to their modular design, the 8-kW SSPAs can be combined to produce even higher power levels. Work is underway to develop an amplifier that will combine three of these 8-kW SSPA modules to achieve a unit with a peak output-power level of 24 kW across the same frequency range. Other configurations that achieve power levels to 32 kW are feasible and being considered for further evaluation.

In another development, Analog Devices is working on an advanced power module, also based on GaN technology,

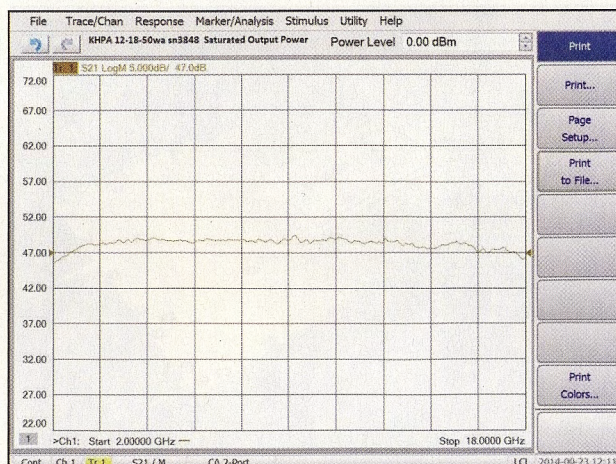
that will double the RF/microwave output power of current modules. Intended to be hermetically sealed, it will support operation in extreme environments. This, along with next-generation combining structures with reduced insertion loss (compared to current approaches), will extend pulsed output power to levels approaching 75 to 100 kW at RF/microwave frequencies. These advanced, high-power SSPAs will include control and processor functionality to enable fault monitoring, built-in-test (BIT) functionality, remote diagnostic testing, and control of fast, real-time, bias-control circuits

for MMIC devices that power the amplifiers.

The GaN-based SSPAs address the industry's need for amplifiers with wide instantaneous bandwidths and high output-power levels. Some systems attempt to meet these requirements using "channelized" or multiple amplifiers, each covering a portion of the required spectrum and feeding a



5. Up to 50-W CW output power from 2 to 18 GHz is possible with this amplifier.



6. This plot displays the output power versus frequency for the 50-W, 2- to 18-GHz power amplifier.

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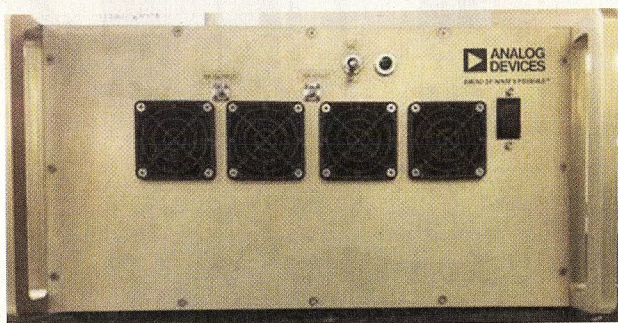


multiplexer. This increases cost and complexity, and results in coverage gaps at the frequency crossover points of the multiplexer. A more effective, alternative solution leverages continuous coverage of wide frequency ranges at elevated power levels, as was accomplished with two different GaN-based amplifiers covering VHF through L-band frequencies as well as 2 to 18 GHz.

AMP VARIETIES

For VHF through S-band frequencies, Analog Devices developed a very small, feature-rich, multiple-octave amplifier capable of 50-W output power from 115 to 2000 MHz. The amplifier achieves output-power levels of +46 dBm (typically 40 W) across that full frequency range when fed with a nominal input signal of 0 dBm. Packed in a 7.3- × 3.6- × 1.4-in. housing, the amplifier includes BIT functionality for thermal and current overload protection, telemetry reporting, and an integrated dc-dc converter for uncompromised RF performance with input supplies ranging from +26 to +30 V dc. Fig. 3 provides a photograph of the amplifier, and Fig. 4 presents typical measured performance data for output power versus frequency.

To address wideband applications above 2 GHz, the company also developed a GaN amplifier that produces 50-W



8. This 2- to 18-GHz solid-state power amplifier produces 100-W CW output power across its full frequency range.

TABLE 2: TYPICAL WIDEBAND SSPA PERFORMANCE

Output power	50 W
Frequency range	2 to 18 GHz
Duty cycle	100%
Input/output VSWR	1.50:1
Out-of-band spurious noise (max.)	-70.0 dBc
Gain stability	2.5 dB
RF input connector	SMA
RF output connector	Type N



7. Across its full frequency range, this wideband 2- to 18-GHz power amplifier is capable of yielding 12-W CW output power.

continuous-wave (CW) output power across the entire 2- to 18-GHz band. This amplifier uses commercially available 10-W GaN MMICs with output-power contributions summed by means of a wideband, low-loss combiner circuit. Multiple amplifiers may in turn be combined to develop output power as high as 200 W across this same 2- to 18-GHz bandwidth. The driver amplifier chain is also based on GaN active devices.

The device operates from +48 V dc and features an internal voltage regulator and high-speed switching circuits to enable pulsed operation with good pulse fidelity and fast rise and fall times. Table 2 lists the amplifier's (depicted in Fig. 5) specifications; while Fig. 6 presents the amplifier's output power as a function of frequency from 2 to 18 GHz.

This 50-W amplifier is one of a family of amplifiers covering the 2-to-18-GHz band. The firm also crafted a compact, benchtop amplifier capable of 12-W output power (Fig. 7) and a rack-mount unit that offers 100-W output power (Fig. 8). Other amplifiers, with frequency coverage from 2 to 6 GHz and 6 to 18 GHz, are under development.

On top of that, Analog Devices is attempting to increase the output power of these broadband amplifiers from their present levels to 200 W and higher. To achieve these higher output-power levels, the company is working on modules with increased output power as well as broadband RF power combiners with much-improved combining efficiency and less loss than current power combiners.

These represent a few examples of the performance levels possible with GaN-based solid-state amplifiers. Unit costs of the amplifiers are expected to decrease as more GaN semiconductor vendors move to larger wafer sizes and continue to improve their yields of devices per wafer. Systems operating at millimeter-wave frequencies will see greater use of GaN devices as gate lengths are reduced, enabling higher frequency operation for GaN-based SSPAs. It's clear that current GaN trends of improving performance and dropping costs will continue for some time. **mw**

Adjusting Amplitude Through Attenuation

Attenuators can control signal amplitudes in a variety of ways, even with attenuation that changes as a function of temperature.

Amplitude control in a system, at various power levels and frequencies, is important for countless reasons. It's a task usually bestowed upon one of the most essential of components—the attenuator. But specifying an attenuator is rarely simple, since system-level applications often require attenuation under very specific operating conditions, and be maintained even as temperature, frequency, and pulse widths change in a system. Attenuators are also available in many different package styles and formats. Therefore, it helps to get a closer look at how the different attenuators perform when attempting to specify an RF/microwave attenuator to a particular application.

Selecting an attenuator for an application requires a great deal of filtering through specifications. Often, it's more than just a simple matter of sorting through performance variables and picking a type of package. That's because some performance limit, such as power-handling capability, will greatly influence the type and size of package.

Tremendous progress has been made in circuit materials and attenuator designs during the last few decades. However, smaller attenuators, such as surface-mount-technology (SMT) components, are still limited in power-handling capabilities compared to larger attenuators in metal packages with coaxial connectors or waveguide signal ports.

EYES ON PIM DISTORTION

Many key performance parameters, such as insertion loss, attenuation accuracy, and power-handling capability, were reviewed in a previous article on attenuators (see "Know When To Add Attenuation," *Microwaves & RF*, April 2015, p. 114). The

article also provided a brief review of the mechanical options for RF/microwave attenuators, including fixed, continuously variable, and programmable attenuators that change attenuation in discrete steps.

One parameter that's growing in importance for various types of attenuators is the passive-intermodulation (PIM) distortion level. Such distortion, found in passive components like cables, connectors, and attenuators, can be caused by the unwanted mixing of multiple signals. Low PIM is critical to achieving dependable performance in cellular base stations and other communications systems using complex modulation schemes.

More companies than ever now offer fixed and variable attenuators with low PIM levels, such as the LPAR50-dB-1WWP series of low PIM fixed attenuators from MECA (www.e-meca.com). Multiple-attenuator configurations are available, including 15, 20, 30, and 40 dB.

Although supplied in somewhat large enclosures (Fig. 1), they are designed to handle high power levels and are capable of 50-W average

power and 2.5-kW peak power from 0.689 to 2.7 GHz. The devices are supplied with 7/16 and Type N connectors insulated with virgin-grade polytetrafluoroethylene material (PTFE) to minimize the generation of PIM at high power levels, even during attenuation of the signal amplitude.

TEMP-VARIABLE ATTENUATORS ON THE RISE

Another trend in RF/microwave attenuators is the growing popularity of temperature-variable attenuators, as circuit and system designers discover the practical applications for these novel devices. These fixed and variable attenuators are fabricated with various thermistor-type materials that exhibit



1. The LPAR50-dB-1WWP series of attenuators can handle 50-W average power and 2.5-kW peak power from 0.689 to 2.7 GHz while maintaining low passive-intermodulation (PIM) distortion. (Courtesy of MECA)

characteristics of changing attenuation with temperature. Firms that offer this type of attenuator typically publish a set of attenuation-versus-temperature responses, which allows designers to select the attenuation with a temperature curve that's most suited to their application.

The technology isn't new. One form of it was actually patented in the early 1990s by EMC Technology (www.emc-rflabs.com). The firm's Thermopad temperature-variable attenuator line is winning over more designers as a solution for RF/microwave amplitude variations caused by changes in temperature.

For example, these attenuators can be used in series with power amplifiers that exhibit variations in gain due to temperature, either from environmental effects or from their own heating effects at high power levels. By selecting a temperature-variable attenuator with an attenuation/temperature response that's close to the inverse of the amplifier's gain/temperature response, the amplifier's output power can be held fairly stable with temperature and without more complex automatic-level-control (ALC) circuits.

The patented technology combines level setting and temperature compensation in a single device, helping reduce component counts and costs. The totally passive Thermopad temperature-variable attenuators add little or no distortion to a system, and can be supplied with attenuation/temperature responses tailored to the needs of a system or circuit, with negative and positive coefficients of attenuation possible.

The Thermopad attenuators have minimal effect on signal phase or time-domain response, which means minimal distortion on complex I/Q signal modulation formats. Models in the company's MTVA line of absorptive RF/microwave attenuators (Fig. 2), for example, come in compact surface-mount housings that are smaller at higher frequencies, and feature attenuation values from 1 to 9 dB at frequencies from dc to 18 GHz.

To introduce designers to the concept of temperature-variable attenuation, the company offers a wideband temperature-variable design kit usable from dc to 20 GHz. With the TVA-DKIT, engineers can explore broadband circuits using attenuators with different temperature coefficients of attenuation (TCA) in components measuring only 0.075×0.060 in. (1.90×1.52 mm). The kit contains attenuators with attenuation values from 2 to 6 dB, as well as a variety of different attenuation-versus-temperature responses for experimentation.

OTHER TEMP-VARIABLE ATTENUATOR OPTIONS

The firm isn't the only one offering temperature-variable attenuators. API Technologies-Inmet (www.inmet.apitech.com) has developed the TCAF N05 Series of temperature-

variable attenuators for applications ranging from dc to 12 GHz. These chip-sized, surface-mountable temperature-variable attenuators come in fixed attenuation values of 2, 3, 4, 5, and 6 dB, with 0.5-dB attenuation accuracy for each attenuation value.

They're designed with a negative attenuation-versus-temperature response of -0.005 dB/°C to compensate for amplitude variations, such as changes in amplifier gain. These attenuators operate with bias or control voltage and can handle power levels to 2 W.

Other players in the temperature-variable attenuator market include Thin Film Technology Corp. (www.thin-film.com) and International Manufacturing Services (IMS, www.ims-resistors.com). Thin Film Technology offers the ATV0805J Series of temperature-variable attenuators in a compact 0805 package style ($0.079 \times 0.049 \times 0.035$ in.). These RoHS-compliant components are fabricated with thermally sensitive thermistor material on alumina substrates. The product line, usable from dc to 10 GHz, is available with attenuation values from 1 to 6 dB and an attenuation tolerance of ± 0.5 dB. They are rated for power levels to 63 mW.

IMS enables circuit designers to tackle effective dissipation of heat through its Thermo-Bridge and Thermo-Plane series of resistive components—the AV-0805

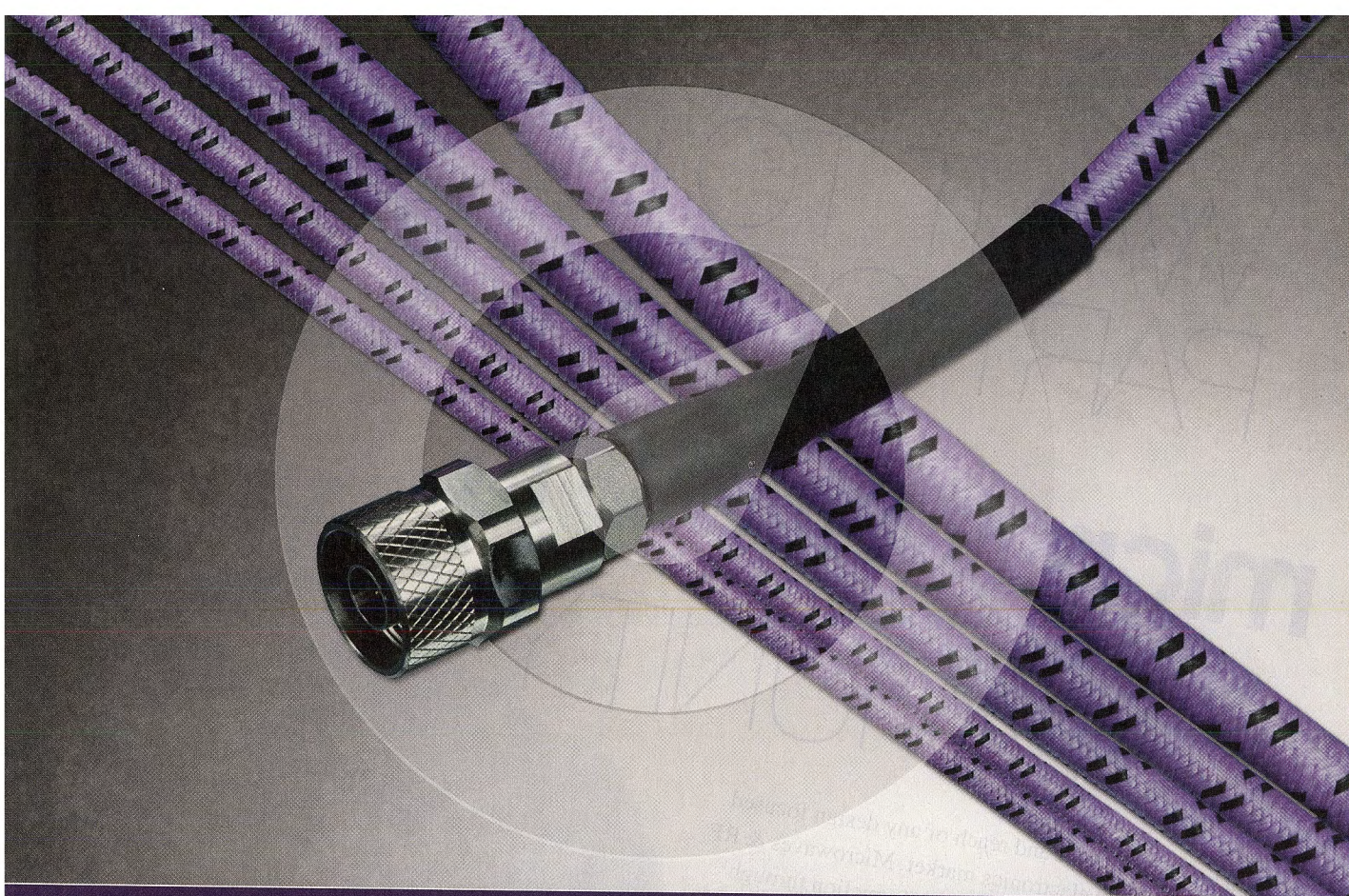
line of thin-film temperature-variable chip attenuators. Fabricated on alumina substrate material, these surface-mount devices are characterized to 5 GHz and available in attenuation values from 1 to 10 dB in 1-dB increments. Eight or nine attenuation-versus-temperature response curves are available for the attenuators, depending on attenuation value. The compact chips operate in the -40 to $+100^\circ\text{C}$ temperature range, and are rated for power levels to 63 mW.

What's been covered in this article represents just a few examples of how attenuators are evolving to handle amplitude-control issues in RF/microwave systems. As demonstrated by MECA's attenuator, high-power handling capabilities still require considerable physical size to dissipate heat, which will ultimately limit the power-handling capabilities of chip-sized attenuators.

Resistive materials continue to advance, though. As a result, more circuit and system designers are discovering the effectiveness of adding attenuation (in particular, temperature-variable attenuation) in series with power amplifiers to help level the amplitude gain response in systems such as cellular-communications base stations, cable-television (CATV) infrastructure equipment, and satellite-communications (satcom) systems equipment. **mw**



2. The MTVA series of temperature-variable attenuators features attenuation values from 1 to 9 dB at frequencies from dc to 18 GHz.
(Courtesy of EMC Technology)



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What's the Difference Between ADCs and DACs?

Data converters have many similarities, though, with both types trending toward smaller packages, increased functionality, and lower operating-power levels.

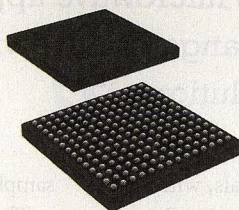
Data converters provide a transition between the analog and digital signal realms. The two basic converter types, analog-to-digital converters (ADCs) and digital-to-analog converters (DACs), share many common circuit elements and even come in similar multi-pin packages. Key performance parameters are identical between the two, including clock speed, sampling rates, and bandwidth, but they differ in many other ways. Ultimately, understanding how the different characteristics can be used to describe an ADC or a DAC will help speed the task of finding an optimum data converter for a particular application.

ADCs sample continuous analog signals over an input voltage range and convert them into digital representations (words) with resolution equal to the ADC's number of bits. Sampling occurs at the ADC's clock frequency. DACs convert digital input code into analog output signals, essentially providing the opposite function of an ADC. Both types rely heavily on the performance of a clock oscillator (or oscillators) to achieve the most precise and repeatable sampling process.

ABCs OF ADCs

An ADC's performance is often presented in terms of both time- and frequency-domain plots. Time-domain plots show the component's voltage as a function of time, whereas frequency-domain plots show signal power as a function of frequency, or the spectral performance, of an ADC.

Spectral performance includes a number of parameters useful for comparing the capabilities of different ADCs, including effective number of bits (ENOB), signal-to-noise ratio (SNR), signal-to-noise and distortion (SINAD), spurious-free dynamic range (SFDR), and total harmonic distortion (THD). Additional ADC parameters, such as bandwidth, clock speed,



This compact housing holds two high-speed ADCs capable of handling signals to 2 GHz at sampling rates reaching 500 Msamples/s.

(Courtesy of Richardson RFPD and Analog Devices)

and current consumption, can aid the task of specifying a commercial ADC for a particular application.

In theory, an ADC's SNR is equal to the number of bits multiplied by 6 dB. For RF/microwave applications, a wide range of ADCs are available with bit resolutions of 8, 12, and 14 b, which would yield respective theoretical SNRs of 48, 72, and 84 b. The sampling rate also impacts ADC noise performance. The faster a signal is sampled, the lower the noise floor, since any noise is spread across more sampled frequencies.

According to Nyquist theory, to accurately convert an analog input voltage into digital code, the input waveform must be sampled at twice the bandwidth of the input signal (rather than twice the frequency of the signal). This would suggest that sampling an input signal with 500-MHz bandwidth requires a 1-Gsample/s sampling rate. Exceeding the Nyquist rate—in this example, that's sampling faster than 1 Gsamples/s—is known as oversampling.

Another ADC operating mode, undersampling, is defined as sampling at a frequency less than one-half of the signal frequency (rather than its bandwidth). The Nyquist frequency equals one-half of the sampling frequency.

Data converters are often characterized as operating in different Nyquist zones, which are defined in terms of the sampling frequency. For example, the first Nyquist zone—the most commonly used zone—ranges from dc to one-half the sampling frequency. The second Nyquist zone is from one-half the sampling frequency to the sampling frequency. And the third

Nyquist zone spans from the sampling frequency to three times the sampling frequency divided by two.

The noise floor of an ADC or DAC relates to the sampling rate. Each time the sample rate is doubled, the noise floor improves by 3 dB. ADCs typically employ digital filtering to remove noise from the target bandwidth of a converter and improve the SNR.

DIVING INTO DACs

A DAC essentially does the opposite of an ADC, converting digital inputs to analog output signals. The analog signals are generated at the sampling frequency applied to the DAC clock. As with an ADC, the key spectral-performance parameters for a DAC include SNR and SFDR. DAC specifiers must also be concerned with a device's adjacent-channel leakage ratio (ACLR) and third-order intermodulation (IMD3). Both are forms of

Data converters for RF/microwave applications extend across a wide range of bandwidths, sampling rates, and bit resolutions.

distortion, yielding unwanted additional signals, with IMD3 related to third harmonics of the clock driving the DAC.

ADCs and DACs may differ dramatically in their functions, but they share many requirements, albeit at different sections of the converter. For an ADC, filtering is often applied to input signals to remove harmonic and spurious content. For a DAC, filtering is added at the other end of the component—the output port—to similarly provide enhanced spectral performance.

One parameter that is of concern for both types of converters is the quality of the clock source, particularly in terms of phase noise and stability. Excessive phase noise of a DAC's clock source, for example, will impact its SNR and SFDR performance. In an ADC, sampling errors will increase with excessive clock phase noise (or jitter in the time domain).

In addition to jitter or phase noise from the external clock that's driving an ADC or DAC, a converter will suffer a certain amount of internal clock jitter inherent to the circuit design, known as aperture jitter. The external and the internal jitter combine to create total jitter that affects the performance of both ADCs and DACs. For example, system designers seeking to achieve output analog waveforms with a defined minimum level of SNR performance must provide a clock source with a certain minimum level of jitter or phase noise.

Clock sources meant to drive ADCs and DACs usually generate continuous sine waves for sampling and signal generation. A square-wave clock source can also be used. However, specifiers must be aware that a possible tradeoff for improved phase noise and jitter may be degraded harmonic performance inherent to the high harmonic content of the square-wave clock signals.

CONVERTER OPTIONS APLENTY

Data converters for RF/microwave applications extend across a wide range of bandwidths, sampling rates, and bit resolutions, since these components are used for many applications, from sampling receiver input signals to generating output signals from transmission. A number of suppliers offer high-quality data converters, including Analog Devices (www.analog.com), Atmel Corp. (www.atmel.com), Intersil (www.intersil.com), Maxim Integrated (www.maximintegrated.com), ON Semiconductor (www.onsemi.com), STMicroelectronics (www.st.com), and Texas Instruments (www.ti.com).

These devices come in a variety of package styles that can be sorted according to parameters, such as sampling rate and bit resolution. One recent trend common to both ADCs and DACs is to incorporate more supporting functions within each data converter circuit in ever-smaller packages and operating at lower power levels. For example, Richardson RFPD (www.richardsonrfpd.com) recently announced its support for Analog Devices' AD9684 ADC. Although supplied in a compact housing (see figure), this is actually two ADCs in one package, designed for

sampling wide-bandwidth analog signals.

The 14-b dual ADC operates at sampling rates to 500 Msamples/s at low power levels and with excellent linearity. The 196-ball, ball-grid-array (BGA) package, which contains an on-chip buffer and sample-and-hold circuit, measures just 12 × 12 mm. The dual ADC circuits feature a multistage, differential pipelined architecture with integrated output error-correction logic. The converter offers dual buffered inputs and an integrated voltage reference.

The AD9684 consumes only 1.1 W per channel when running at 500 Msamples/s. It achieves a full-scale SFDR of 85 dB for a 170-MHz input signal, and a full-scale SNR of 68.6 dB for the same input signal at a 500-Msample/s rate. The device well represents the trends in data converters, providing increased functionality in smaller packages and operating at lower power levels.

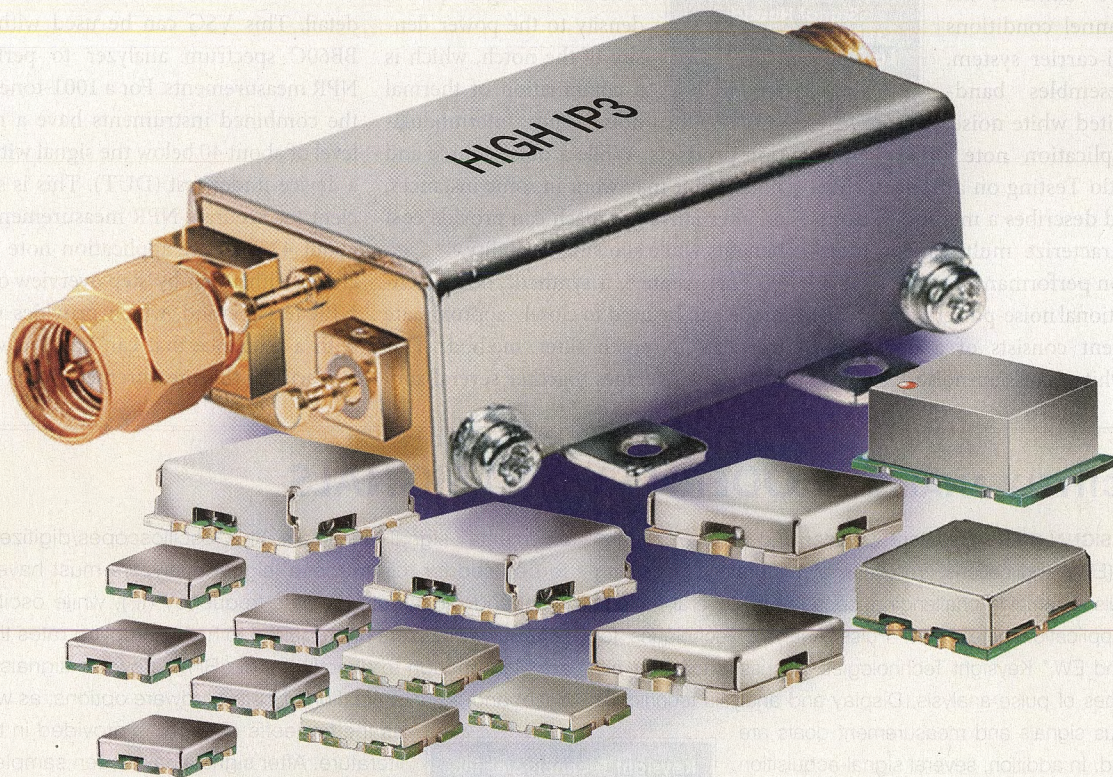
Higher sampling rates are also readily available. One such example is the direct-RF-sampling ADCs from Texas Instruments, which handle input signals to beyond 3 GHz at sampling rates to 4 Gsamples/s and 12-b resolution.

In effect, a wide-bandwidth, high-sampling-rate ADC can replace a portion of a radio front end. For instance, it's able to replace one intermediate-frequency (IF) section (and its associated components, including mixers, oscillators, and amplifiers), thus reducing circuit size and cost for the radio design. Potential savings in operating power when using this current generation of ADCs and DACs can also reap tremendous dividends for customers of portable radios and other types of electronic products. www.richardsonrfpd.com

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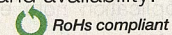


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USE A SYNTHETIC NOISE TECHNIQUE TO MEASURE NOISE POWER RATIO

INTERMODULATION DISTORTION (IMD) needs to be measured in many scenarios, as it is often a critical parameter. For example, two-tone third-order intercept-point (IP3) testing is suitable for a number of applications. Yet it is not always the most effective approach to simulate the actual channel conditions of a multi-carrier system, which resembles bandwidth-limited white noise.

In an application note titled "Noise Power Ratio Testing on a Budget," Signal Hound describes a method to accurately characterize multi-carrier intermodulation performance.

A traditional noise-power-ratio (NPR) measurement consists of a broadband additive-white-Gaussian-noise (AWGN)

source that spans the entire bandwidth of the actual test. A notch filter, which has a deep and narrow notch somewhere within this bandwidth, is also included in the test setup. Typically, the notch's bandwidth is no greater than 10% of the total bandwidth. The noise power ratio is the

ratio of the signal power density to the power density of the notch, which is a combination of thermal noise and intermodulation products. While a noise source and notch filter may work in some instances, an alternative approach can provide cost benefits while allowing flexibility.

For instance, a synthetic noise technique can be used to closely approximate the AWGN/notch filter method. This technique averages together several suc-

cessive measurements using 1000-tone sets that have random phase relationships. A vector signal generator (VSG) with a 100-MHz bandwidth can provide the capability required to measure NPR with the synthetic noise method.

The capabilities of Signal Hound's VSG25A model are discussed in further detail. This VSG can be used with the BB60C spectrum analyzer to perform NPR measurements. For a 1001-tone test, the combined instruments have a noise level of about 40 below the signal without a device-under-test (DUT). This is sufficient for accurate NPR measurements to about 42 dB. The application note concludes with a step-by-step overview of the NPR test method, which provides users with a reference that can be used when performing this measurement.

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EFFECTIVELY ANALYZE MODERN PULSED SIGNALS

PULSED SIGNALS ARE prevalent in radar and other electronic-warfare (EW) applications. The task of accurately measuring these pulses remains challenging because of several factors. In the application note, "New Pulse Analysis Techniques for Radar and EW," Keysight Technologies discusses tools for different types of pulse analysis. Display and analysis techniques for various signals and measurement goals are described. In addition, several signal-acquisition and processing technologies are presented.

In the past, swept spectrum analyzers were generally used to perform basic pulse measurements. This approach was adequate for simple pulses and signal environments containing only a single pulse train. But modern systems use much more complex pulses. A number of different pulses from one or multiple emitters may be included in many signal environments. Because of the combination of complex signals and detailed measurement requirements, pulse measurements must be performed using digital-signal-processing (DSP) techniques on sampled and digitized signal information.

The application note examines two different RF/microwave hardware platforms that can be used for pulse mea-

surements: signal analyzers and oscilloscopes/digitizers. To be used for this purpose, signal analyzers must have a wideband digital intermediate-frequency (IF), while oscilloscopes or digitizers are required to have sampling rates that are high enough to directly handle RF/microwave signals at baseband. An examination of both hardware options, as well as the tradeoffs of each, is provided in the literature. After signals have been sampled, a variety of software solutions are available for analysis needs. A description of those options also is included.

The pulse analysis process is described as a sequence of three steps, which is explained in detail. Various techniques used to meet the challenges of analyzing complex pulse environments are discussed, such as IF and frequency mask triggering. The segmented memory feature, which enables oscilloscopes to capture a significantly greater number of pulses, is explained as well. Additionally, a new pulse measurement option for the 89600 vector-signal-analysis (VSA) software is presented, as this feature enables the analysis results of large numbers of pulses to be organized in tabular or graphical form.

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Handheld Analyzers Conquer 50 GHz

Keysight's FieldFox handheld analyzers provide extended frequency ranges to 50 GHz and multiple measurement functions in housings even smaller than laptop computers.

FieldFox handheld analyzers from Keysight Technologies (www.keysight.com) have already demonstrated their effectiveness for field and laboratory measurements at RF/microwave frequencies. However, to inject even more flexibility into the analyzer family, the company recently developed six new members for millimeter-wave frequency coverage to 50 GHz (Fig. 1).

Ideal for maintenance and troubleshooting of systems such as satellite-communications (satcom) earth stations, line-of-sight communications links, and radar systems, the analyzers offer different performance levels for use to 32, 44, and 50 GHz.

Each unit can replace

three or more separate test instruments, including spectrum analyzers, vector network analyzers (VNAs), power meters, etc.

SPECTRUM AND COMBO ANALYZERS

This latest series of millimeter-wave analyzers consists of three models that are solely spectrum analyzers and three models that combine the functions of multiple instruments, including spectrum analyzers, cable and antenna analyzers, and VNAs. Each compact instrument features a straightforward layout, with clear display screen, large keypad for data entry and control, and top-mounted connectors for ease of linking signal inputs and outputs. All six models, as well as earlier models, offer a built-in power meter and can perform pulse, channel power, and interference measurements, as well as others.

The three new combination analyzers cover 32, 44, or 50 GHz and provide spectrum analysis, vector network analysis, and cable and antenna testing among their measurement capabilities. The three spectrum-analyzer models cover the same frequency ranges (*see the table*). All FieldFox analyzers are well-suited for field use; the combination analyzers with their additional measurement functions also prosper as laboratory instruments.

The analyzers are designed for tough conditions—they comply with US MIL-PRF-28800F Class 2 standards and are type-tested to meet MIL-STD-810G requirements for operation in explosive environments (Method 511.5, Procedure 1). Circuitry is contained in sealed enclosures with no fans or vents, and even test connectors are mounted in a connector bay at the top of each instrument for protection from mishandling. The rugged enclosures are also type-tested to meet IEC/EN 60529 IP53 requirements for protection from dust and water.



1. The latest additions to the FieldFox line of portable analyzers include two sets of models with top frequencies of 32, 44, and 50 GHz for testing at millimeter-wave frequencies.

Each enclosure includes a side strap for ease of transport, and test results are shown on an antiglare 6.5-in.-diagonal liquid-crystal-display (LCD) screen with light-emitting-diode (LED) back light. The FieldFox analyzers measure just 11.5 × 7.4 in. (292 × 188 mm) and they weigh only 7.1 lbs. (3.2 kg) with their rechargeable lithium-ion battery.

The impressive circuitry shared by all six new FieldFox models matches any of today's larger, benchtop spectrum analyzers. Resolution bandwidth filters range from 10 Hz to 5 MHz wide, with video bandwidth filters from 1 Hz to 5 MHz. The analyzers deliver high stability and low noise for in-field measurements, as evidenced by phase noise offset 10 kHz from a 1-GHz carrier at typically -111 dBc/Hz, and phase noise offset 1 MHz from the same carrier typically dropping to -113 dBc/Hz.

Without any warm-up, the FieldFox analyzers deliver typical amplitude accuracy of ±0.35 dB from 100 kHz to 18 GHz and ±0.5 dB from 18.0 to 26.5 GHz. Typical amplitude accuracy through 50 GHz is ±0.5 dB. The displayed average noise level (DANL) is also remarkable, at typically only -157 dBm from 2.1 to 2.8 GHz, -152 dBm from 7 to 13 GHz, -149 dBm from 13 to 22 GHz, and -135 dBm or better from 40 to 50 GHz.

OUT IN THE FIELD

Of course, having multiple measurement functions in a handheld unit encourages its use in the field (Fig. 2). The cable and antenna analyzer can perform testing on in situ cables in systems, including one-port cable-loss measurements and two-port insertion-loss measurements. It can also perform time domain reflectometry (TDR) in search of faults in cables and coaxial connections, as well as perform distance-to-fault (DTF) measurements to find the precise location of a cable fault. In fact, these higher-frequency analyzers are available with a long list of accessories, including waveguide adapters for use at higher frequencies (Fig. 3).

But the cable and antenna analyzer is just one side to this multiple-function instrument. As microwave VNAs, these analyzers are able to provide calibrated measurements on popular scattering parameters, such as S_{21} . However, they can also be used for full two-port measurements on all four S-parameters, including magnitude and phase as well as time-domain analysis. A number of useful applications notes are available for these analyzers, and cover FieldFox measurements to 50 GHz.

With the "CalReady" feature, which is the built-in calibration capability, the portable analyzers are ready to perform S-parameter measurements, DTF testing, and time-domain reflectometry (TDR) without connecting additional equipment to do a calibration. In addition, they can be quickly calibrated over broad frequency rang-



2. The light weight, small size, and multiple functions of the new FieldFox analyzers suit them for in-field testing, including at high-frequency satellite earth stations. (Courtesy of INTELSAT)

es, enabling them to perform accurate, calibrated measurements over broad bandwidths. The analyzers also support traditional mechanical and e-Cal calibration kits as used with benchtop RF/microwave analyzers.

When equipped with the spectrum-analyzer gating option (Option 238), FieldFox instruments provide gated fast Fourier transform (FFT) capability. This enables the capture and analysis of high-speed pulsed signals. Pulse-viewing capability is a function of the gate time. For example, with a short gate time set from 6 μs to 1.8 s, multiple pulses with short rise and fall times can be captured and viewed for analysis. FieldFox functions such as automatic trigger delay and bandwidth settings help simplify testing on pulsed signals.

FieldFox analyzers contain an integral test signal source, operating to 50 GHz depending on the model. The signal source can be tuned to any frequency, independent of the spectrum-analyzer frequency, or act as a traditional tracking generator.

Another useful function for checking and characterizing high-frequency cables is the extended range transmission analysis (ERTA) option offered with the spectrum-analyzer functionality. Such measurements require analyzers with high dynamic range and fast measurement speed, especially when checking over long lengths of cable where much test data will be developed. Microwave scalar network analyzers (SNAs) traditionally perform such measurements, although they have always been benchtop in nature and limited in their usefulness for in-field measurements.

FieldFox analyzers with the ERTA capability provide the means to measure dynamic ranges as large as 108 dB at 6 GHz and 77 dB at 26.5 GHz without calibration or warm-up period.

The ERTA process requires two FieldFox analyzers, one placed at each end of a cable to be analyzed. One of the analyzers serves as a test signal source while the other acts as a test receiver. By using Keysight's proprietary InstAlign technique, cable-loss measurements can be made across long runs of coaxial cable with ±0.7-dB accuracy.

SIX NEW FIELDFOX HANDHELD ANALYZERS AT A GLANCE

Model	Description
N9950A	32-GHz combination analyzer
N9951A	44-GHz combination analyzer
N9952A	50-GHz combination analyzer
N9960A	32-GHz spectrum analyzer
N9961A	44-GHz spectrum analyzer
N9962A	50-GHz spectrum analyzer

OTHER BUILT-IN FEATURES

Each new millimeter-wave FieldFox analyzer incorporates a built-in variable dc supply for powering probes, external bias tees, and amplifiers under test. The analyzers achieve calibrated measurement accuracy without the tedious mechanical calibration via a Keysight function known as QuickCal (which is usable to 18 GHz).

A built-in GPS satellite receiver provides geographic-location tags for measurements. The time, latitude, longitude, and elevation can be displayed with a measurement for ease of record keeping. In addition, each analyzer includes multiple USB ports and a LAN port plus standard programming commands for programmable instruments (SCPI).

An iOS device, such as an iPhone, iPad, or iPod Touch device can be used to remotely operate the FieldFox analyzers. The Remote View iOS application software provided with each instrument emulates the analyzer's front panel on the iOS device, allowing a user to activate any control key remotely from the iOS device. In addition, the complimentary FieldFox Data Link software simplifies data transfer, data definition, and



3. The FieldFox analyzers with cable and antenna analyzers can be ordered with numerous options to further enhance the testing of cables and waveguide assemblies.

report generation. The software makes it possible to add markers and limit lines to traces and load different files and factors to help create meaningful records of high-frequency measurements.

From their appearance, the analyzers don't present the image of "benchtop austerity" offered by larger, rack-mount laboratory instruments. Still, they can match those larger instruments in terms of measurement performance and accuracy. Plus, they're truly portable, fitting in the palm of a hand. The analyzers weigh only 7.1 lb. (3.2 kg) with battery and will typically run for 3.5 hours when charged.

FieldFox analyzers come loaded with the measurements needed to characterize cables and other components in the field, including DTF, insertion loss, return loss, and VSWR in a single test sweep. In addition, they provide the means to monitor signals in the environment to 50 GHz.

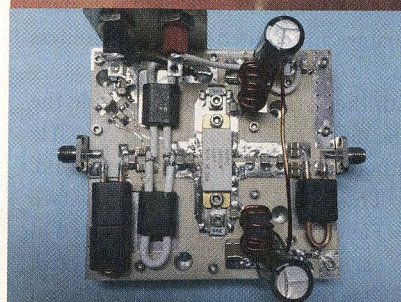
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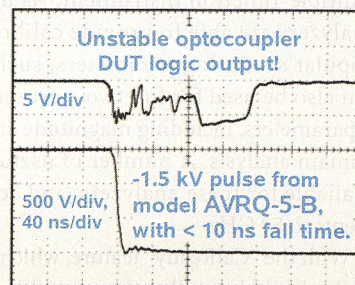


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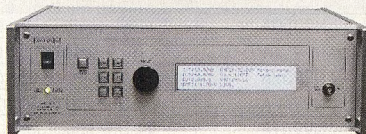
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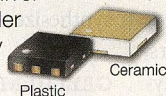
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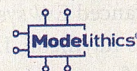
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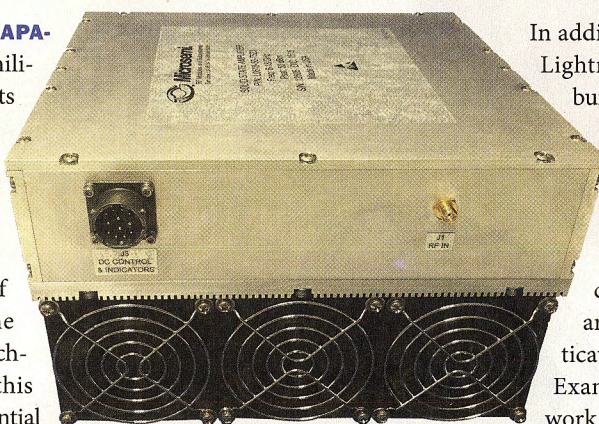
With today's focus on electronic-warfare (EW) capability, the RF/microwave industry is working on satisfying EW requirements in power amplifiers (PAs), low-noise amplifiers (LNAs), complex assemblies, and more.

ELECTRONIC-WARFARE (EW) CAPABILITY

is a prominent aspect of military technology. To demonstrate its importance, the Pentagon created the Electronic Warfare Programs Council earlier this year. That group was launched to focus on EW strategies and innovations across the entire Department of Defense (DoD). For decades, the U.S. military had demonstrated technological superiority. However, this dominance has diminished as potential adversaries have placed emphasis on EW. Although the U.S. has traditionally seen EW as a supporting technology, other nations consider EW to be more of a core weapon. The Pentagon is hopeful that the launch of this group will help the U.S. military win the EW competition.

EW can be defined as any military action that involves the use of electromagnetic (EM) and directed energy to control the EM spectrum or attack the enemy. Its core purpose is to deny the opponent the advantage of the electromagnetic spectrum. EW can be applied from air, sea, land, and space. Its three major subdivisions are electronic attack (EA), electronic protection (EP), and electronic support (ES). For those who wish to learn more about EW, the *Electronic Warfare and Radar Systems Engineering Handbook* is a comprehensive handbook that is designed to aid EW and radar systems engineers.

Advanced EW systems are provided by defense contractors, such as Raytheon, Lockheed Martin, and BAE Systems. Raytheon, for example, provides jammers, decoys and other products. The company was awarded the Next-Generation Jammer (NGJ) program in 2013. That program will integrate advanced electronic attack capability into the EA-18G Growler jet.



1. This PA provides 100 W of saturated output power over a frequency range of 6 to 18 GHz. (Courtesy of Microsemi)

In addition, the Lockheed Martin F-35 Lightning II fighter jet has advanced built-in EW capabilities. These capabilities enable the F-35 to locate and track enemy forces, jam radio frequencies, and disrupt attacks with exceptional precision. All three variants of the F-35 carry active electronically scanned array (AESA) radars with sophisticated electronic attack capabilities. Examples include false targets, network attack, advanced jamming, and algorithm-packed data streams. This system allows the F-35 to reach well-defended targets while sup-

pressing threatening enemy radars.

To enable these critical EW capabilities, the RF/microwave industry is providing numerous solutions. Many components and assemblies intended for EW applications are available from a wide range of suppliers. Gallium-nitride (GaN) technology is playing a major role, as GaN devices are being used to develop power amplifiers (PAs) that satisfy EW performance requirements. GaN technology is also being utilized to develop other components, such as low-noise amplifiers (LNAs). Broadband LNAs that are well suited for EW applications are available from various suppliers. Additional products on the market include integrated microwave assemblies (IMAs), frequency synthesizers, and more.

GALLIUM-NITRIDE POWER AMPLIFIERS

GaN technology has advanced, allowing PAs for EW applications to be designed with high-power GaN devices. Many broadband PAs are utilizing this technology, as companies are taking advantage of the benefits it can offer. GaN-based

PAs have even replaced traveling-wave-tubes (TWTs) in some instances.

One of Qorvo's focal points has been GaN technology. To support EW requirements, the company offers a selection of GaN PAs that can be used to meet these needs. An example is the TGA2214, which provides 5 W of saturated output power from 2 to 18 GHz. It also achieves greater than 20% power-added efficiency (PAE). The TGA2590 is another device that can be used to satisfy EW requirements, as this 30-W PA covers 6 to 12 GHz.

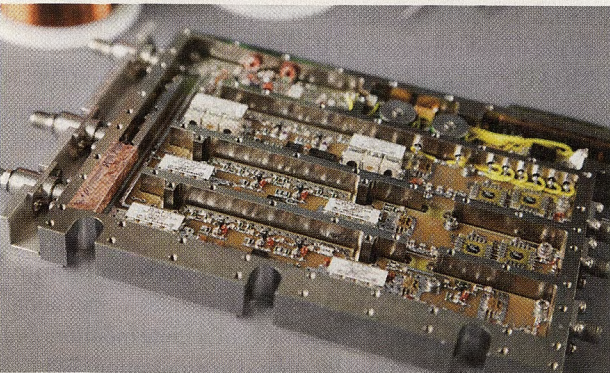
For its part, Microsemi is utilizing GaN technology to develop high-power solutions for EW systems. Two recently released PAs demonstrate the company's support of EW applications: the L0618-50-T523 (Fig. 1) and the AML218P4013. Both PAs utilize GaN technology to achieve high power over a broadband frequency range. The L0618-50-T523, which is intended for land-mobile EW applications, provides 100 W of saturated output power from 6 to 18 GHz. The AML218P4013, which is also well suited for EW applications, is a 20-W PA that spans 2 to 18 GHz.

With its focus on GaN technology, Empower RF is supplying a variety of broadband electronic attack amplifiers. These PAs, which cover 20 MHz to 6 GHz, are intended for airborne, ground, man-pack, and shipboard platforms. The company offers both PA modules and PA systems.

BROADBAND LOW-NOISE AMPLIFIERS

Obviously, EW communications require more than just PAs. A typical EW receiver, for example, incorporates many components like LNAs, filters, and mixers. LNAs are an extremely important component in EW receivers. In addition to their low noise figure, LNAs used in the RF stage of an EW receiver must have a wide frequency range.

Broadband LNAs that are well suited for EW systems are offered by companies like Custom MMIC. Among the company's selection of LNAs is the CMD157. This LNA spans 6 to 18 GHz while providing a gain of 25 dB. According to its datasheet, the CMD157 has a typical noise figure of 1.8 dB from 6 to 9 GHz, while achieving a typical noise figure of 1.5 dB from 9 to 18 GHz.



2. These phase frequency detectors cover 2 to 6 GHz. They can perform pulse measurements and output data in just 15 ns. (Courtesy of API Technologies)

The CMD194C3, which covers 6 to 20 GHz, is another broadband LNA that is ideally suited for EW systems. According to its datasheet, the CMD194C3 typically achieves 20 dB of gain with a noise figure of 2.1 dB across its entire frequency range.

The aforementioned Qorvo also provides a selection of wide-band LNAs that can meet the needs of EW requirements. The TGA2227, for example, is a GaN-based LNA that operates from 2 to 22 GHz. It has a gain of 15 dB with a midband noise figure of 2 dB. In addition, the TGA2567-SM is another LNA that can support EW applications. This LNA spans 2 to 20 GHz, providing 17 dB gain along with a 2-dB midband noise figure.

ADDITIONAL ELECTRONIC-WARFARE PRODUCTS

Many additional products for EW applications are available from various suppliers. API Technologies, for example, offers a selection of EW products that includes PAs, frequency synthesizers, filters, mixers, switched-filter banks, IMAs, and more. For example, the company offers a phase frequency detector that covers 2 to 6 GHz (Fig. 2). It can measure an RF pulse and output data in only 15 ns.

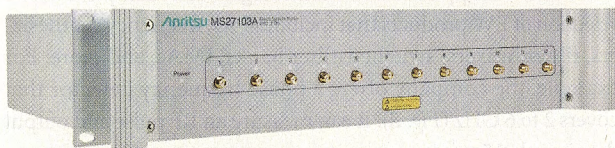
The company's products are intended to address defense requirements for areas like radar warning receivers, Global Positioning System (GPS), jamming/anti-jamming, signals intelligence, portable communications, and radar monitoring systems. "Today's needs for size reduction and affordability in government programs has become a driving force in shaping the EW landscape, and is presenting a challenge to manufacturers," says Dennis Barrick, technical marketing director at API Technologies. He adds: "API is designing components and assemblies with a smaller footprint. In addition, we are providing multi-function assemblies as retrofit solutions which maximize a program's sustainability."

Additional companies offering EW products include Teledyne Microwave, Crane Aerospace & Electronics, and Anaren, to name a few. Teledyne Microwave offers a wide range of products for the EW market, including solid-state power amplifiers (SSPAs), TWTs, frequency-generation products, IMAs, filters, and more. Crane Aerospace & Electronics offers the Electronic Warfare VPX product line, which includes the Modular Quad IF Up & Down Converter, the Modular Direct Synthesizer, and the Modular Seven Channel Indirect Synthesizer. In addition, Anaren offers a selection of EW products like power detection components and instantaneous-frequency-measurement (IFM) receivers. These are just some examples of the offerings currently available, as additional products are available from companies throughout the industry.

Suppliers can expect to help enable military technology by providing EW products. These products will remain crucial in the days ahead. A vast assortment of offerings is currently available to meet the demands of EW applications. The number of products and solutions is only expected to increase as we move toward an EW-protected future. **mw**

Modular System Monitors Spectrum Remotely

This measurement system, designed to be remotely controlled over the Internet, detects and records interference and signals within a particular portion of radio spectrum.



SPECTRUM IS INVALUABLE and irreplaceable, so much so that monitoring signal activity is one way to help safeguard it. Ideally, spectrum monitoring can be performed accurately and from convenient locations. Anritsu Co. delivers that capability with the MS27102A Remote Spectrum Monitor—a modular, scalable, high-performance measurement system that keeps track of interference to optimize use of available frequency spectrum resources. It offers outstanding spurious performance for accurate monitoring of signal activity in frequencies and bandwidth of interest, and can sweep across a total frequency range of 9 kHz to 6 GHz.

The instrument provides 12 RF (female SMA) input ports with an option for 24 input ports (*see figure*). It also includes an Ethernet interface for remote control and two USB ports for memory expansion or to connect a wireless modem.

It searches for licensed and unlicensed signal activity at sweep rates as fast as 24 GHz/s for a 3-MHz resolution bandwidth (RBW) using an instantaneous fast Fourier transform (FFT) bandwidth of 20 MHz. The fast scan/sweep rates make it possible to detect and record even fast transient signals. When using three or more monitors, power-of-arrival (POA) algorithms monitor for interference and calculate the approximate location of an interfering signal source.

There's no video display or keyboard built into the Remote Spectrum Monitor; rather, it relies on sophisticated software and automatic functions accessed and controlled by remote communications (wired or wireless) to perform surveillance, interference detection, and radio spectrum monitoring. The IP67-rated device is designed for outdoor use; it can be wall- or pole-mounted and operates from -10 to $+55^{\circ}\text{C}$. For example, it could be installed in the base transceiver station (BTS) of a wireless comm system to monitor received signals at the BTS.

The Remote Spectrum Monitor is a 12- or 24-input-port unit with measurement capability to 6 GHz. It performs high-speed sweeps and scans of occupied bandwidth in search of interference and other "problem" signals.

The monitor's modules consume less than 11 W for input voltages of $+11$ to $+24$ V dc. They provide spectrogram and signal-strength measurement capabilities for interference analysis across a dynamic range of better than 106 dB normalized to a 1-Hz measurement bandwidth. An integral preamplifier can be switched on and off. When on, the displayed average noise level (DANL) is better than -105 dBm referenced to a 1-Hz bandwidth. System phase noise is -99 dBc/Hz offset 10 kHz from a 1-GHz carrier. Residual spurious levels are -80 dBm with the preamplifier off and -95 dBm with it switched on.

WEB SAVVY

The Remote Spectrum Monitor features an integrated web server that, once connected on the Internet, allows remote operators to access it from anywhere in the world via the Internet. Remote operators can adjust frequency, RBW, and video-bandwidth (VBW) filters (both 10 Hz to 3 MHz), as well as reference levels. It also allows for remote viewing of captured data and measurements over the Internet.

The MS27102A, based on a Linux operating system (OS), is backed by a number of optional software application programs for remote monitoring, including the Vision software tools. Vision Monitor software automatically records spectrum data into a database history, and Vision Locate can locate signals of interest (but it requires three or more monitors).

The 18.9- $\times$ 11.8- $\times$ 3.5-in. Remote Spectrum Monitor weighs 8.9 lb. for the 12-port version. It includes a "watchdog" timer to ensure the long-term stability of remote monitors and a GPS receiver for time and location synchronization. www.anritsu.com

ANRITSU CO., 1155 East Collins Blvd., Ste. 100, Richardson, TX 75081; (800) 267-4878, (972) 644-1777, FAX: (972) 671-1877, www.anritsu.com

HIGH POWER

5 - 500 WATTS PRODUCTS

POWER DIVIDERS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] $\diamond$	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.] $\ast$	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	2	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316
4-WAY								
CSDK3100S	30 - 1000	0.7 / 1.1	0.05 / 0.2	0.3 / 2.0	28 / 20	1.15:1	5	169S

$\ast$ With matched operating conditions

HYBRIDS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] $\diamond$	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

$\diamond$ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] $\ast$	Package
KFK-10-1200	10 - 1200	40 $\pm$ 1.0	$\pm$ 1.5	0.4 / 0.5	22 / 14	150	376
KDS-30-30	30 - 512	27.5 $\pm$ 0.8	$\pm$ 0.75	0.2 / 0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 $\pm$ 1.0	$\pm$ 0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 $\pm$ 1.0	$\pm$ 0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 $\pm$ 1.0	$\pm$ 0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 $\pm$ 1.0	$\pm$ 0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 $\pm$ 0.75	$\pm$ 0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 $\pm$ 1.5	$\pm$ 2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 $\pm$ 1.5	$\pm$ 2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 $\pm$ 1.5	$\pm$ 2.8	0.7 / 1.0	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 $\pm$ 1.5	$\pm$ 2.8	0.7 / 1.0	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 $\pm$ 2.0	$\pm$ 2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 $\pm$ 2.0	$\pm$ 2.0	0.45 / 0.75	14 / 5	25	322
KEK-1317	13000 - 17000	30 $\pm$ 1.0	$\pm$ 0.5	0.4 / 0.6	30 / 15	30	387

* Add suffix - LF to the part number for RoHS compliant version.

$\ast$ With matched operating conditions

Unless noted, products are RoHS compliant.



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 Web: WWW.SYNERGYMWAVE.COM
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Arbitrary Waveform Generator Reaches 32 GHz

ARBITRARY WAVEFORM GENERATORS (AWGs) can define desired signals in the digital realm and use high-speed data converters to produce different types of test signals. In this class of signal generator, the modular model M8196A AWG from Keysight Technologies sets a new bar for performance, with sampling rates of 83 to 92 Gsamples/s, 8-b vertical resolution, and analog bandwidths to typically 32 GHz.

The AWG, based on the AXIe modular instrument format, can provide 1, 2, or 4 synchronized channels per one-slot-high AXIe module (with additional channels enabled via software license). It's able to produce single-ended and synchronized, dual-polarization, independent in-phase/quadrature (I/Q) differential signals at impressive speeds and bandwidth.

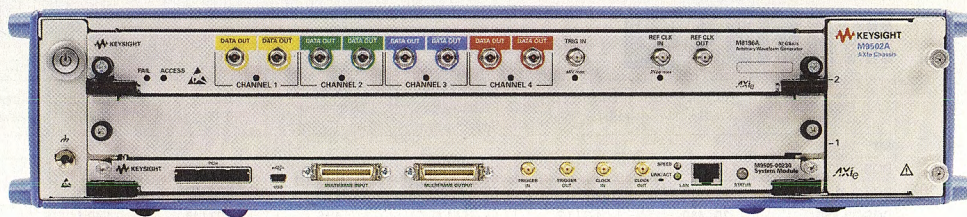
For instance, the M8196A generates modulated signals at rates to 64 Gbaud, defining and storing waveforms with the aid of 512 ksamples of waveform memory per channel. It can create almost any form of multilevel modulation, including mathematically defined arbitrary waveforms, short pulses, and multi-gigahertz chirped signals. High-speed digital signals are possible, as are analog signals with

advanced modulation and signals for testing wideband photonics systems.

The instrument achieves as much as 2 V_{P-P} differential output voltage and adjustable dc offset in a -1- to +2.5-V dc window. It has built-in frequency and phase-response calibration for generating clean signals, exhibiting better than -115 dBc/Hz single-sideband phase noise offset 10 kHz from a 1-GHz sine-wave carrier.

The model M8196A AWG can attain pulsed rise/fall times of better than 9 ps. This compact yet sophisticated signal source fits into a one-slot modular AXIe housing with female 2.4-mm coaxial connectors. In addition, it operates in continuous and triggered (with an external trigger) run modes. Entry price is \$140,000.

KEYSIGHT TECHNOLOGIES INC., 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2663, www.keysight.com



The M8196A arbitrary waveform generator provides analog-output bandwidths to 32 GHz by merit of its 83- to 92-Gsample/s sampling rates.

MM-Wave Amplifiers Extend Past 96 GHz

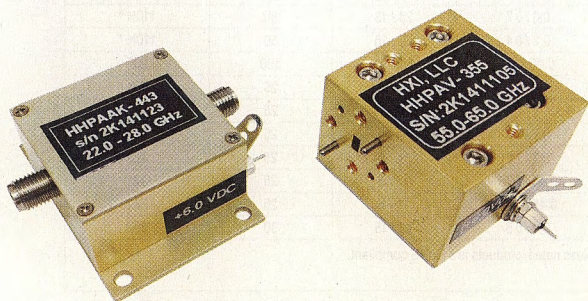
THE HMPA AND HHPA LINES of millimeter-wave power amplifiers from HXI Millimeter Wave Products have grown with the addition of a dozen new models covering a total frequency range of 17 to 96 GHz. Well-suited for applications in communications systems, radar systems, and test equipment, the amplifiers combine high gain and respectable output power at 1-dB compression with the ease of a single bias supply. The amplifiers are built on proven mono-

lithic-microwave-integrated-circuit (MMIC) device technology, and come in compact housings with coaxial or waveguide connectors.

As an example, model HHPAB2.4-511 operates from 40.0 to 47.5 GHz with 15-dB typical gain and +23-dBm output power at 1-dB compression. It's equipped with 2.4-mm female coaxial connectors. For a somewhat higher frequency range, the new model HHPAV-510 offers a bandwidth of 50.0 to 66.0 GHz. It features 34-dB typical gain with +14-dBm typical output power at 1-dB compression. It's supplied with WR-15 waveguide connectors.

Toward the high-frequency upper limits of the amplifier family, model HPAW-530 covers the 4-GHz bandwidth from 92.0 to 96.0 GHz using WR-10 waveguide input and output connectors. It achieves +15-dBm output power at 1-dB compression with 30-dB typical small-signal gain. For improved reliability and ease of use, each amplifier contains an internal voltage regulator and bias sequencing circuitry.

HXI MILLIMETER WAVE PRODUCTS, 12 Lancaster County Rd., Harvard, MA 01451; (978) 772-7774, FAX: (978) 772-7775, e-mail: MWcomponents@hxi.com, www.hxi.com



The HMPA and HHPA series of power amplifiers were expanded to include high-gain models with coaxial connectors and waveguide operating through 96 GHz.

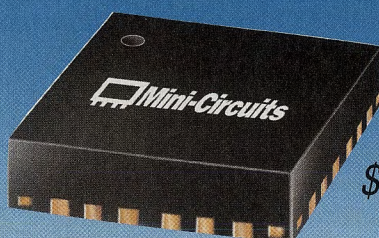
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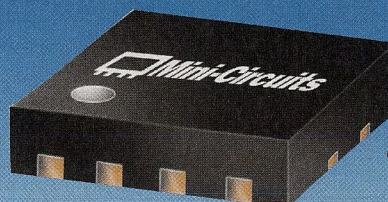
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MMIC Amplifiers

Noise Figure, 0.46 dB
1.1 to 4.0 GHz



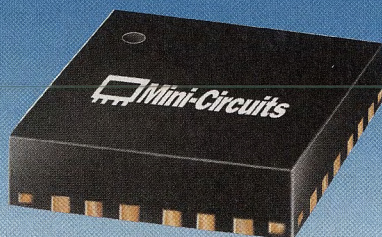
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PMA2-43LN+

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- ✓ High gain, up to 23 dB
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- ✓ High IP3, up to +33 dBm
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- ✓ Tiny size, 2 x 2mm

MMIC Mixers

2200 to 7000 MHz



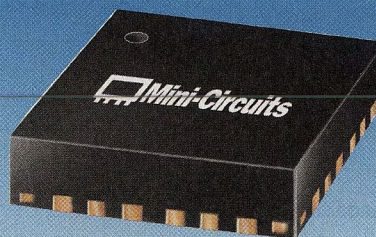
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- ✓ LO power, +15 dBm
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MMIC Mixer-Amplifiers

2200 to 7500 MHz



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- ✓ LO power, 0 dBm
- ✓ Tiny size, 4 x 4mm

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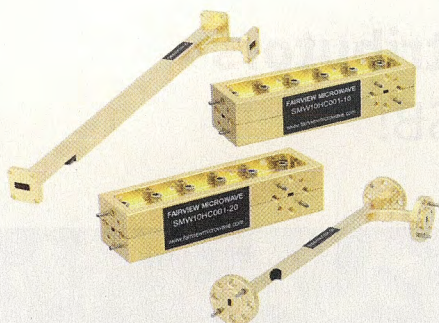
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Waveguide Couplers Direct Signals to 110 GHz

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LVPECL Oscillator Extends to 156.250 MHz

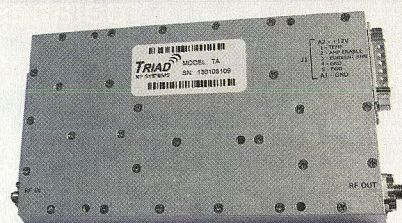
MODEL CCPD-575 is a low-voltage, positive-emitter-coupled-logic (LVPECL) crystal oscillator that operates from 50.000 to 156.250 MHz with ± 20 ppm stability and aging rate of better than 3 ppm. The source draws 80 mA typical current from a +3.3-VDC supply. The phase noise is better than -120 dBc/Hz offset 100 Hz from a 100-MHz carrier and better than -154 dBc/Hz offset 10 kHz from the same carrier. The typical phase jitter is 85 fs offset 12 kHz to 20 MHz from a 100-MHz carrier. The oscillator is designed for an operating temperature range of -40 to +85°C. It is supplied in a 5.0 x 7.5 mm surface-mount-device (SMD) package. It meets the applicable requirements of MIL-STD-883 and MIL-STD-202.

CRYSTEK CORP., 12730 Commonwealth Dr., Fort Myers, FL 33913;
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Amplifier Module Boosts 800 to 2500 MHz

LINEAR AMPLIFIER module model TA1148 provides 12-W output power from 800 to 2500 MHz and is well suited for a variety of applications, including for Third-Generation (3G) and Fourth Generation (4G) cellular communications systems. Based on gallium arsenide (GaAs) device technology, the amplifier module achieves 40-dB linear gain across its bandwidth with gain flatness of ± 1 dB. The unit draws 5.5 A current from a +12-



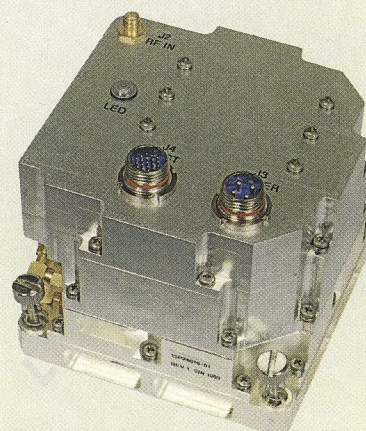
VDC supply at 100% duty cycle and exhibits rise/fall times of better than 1 μ s. It measures 6.0 x 3.5 x 0.693 in.

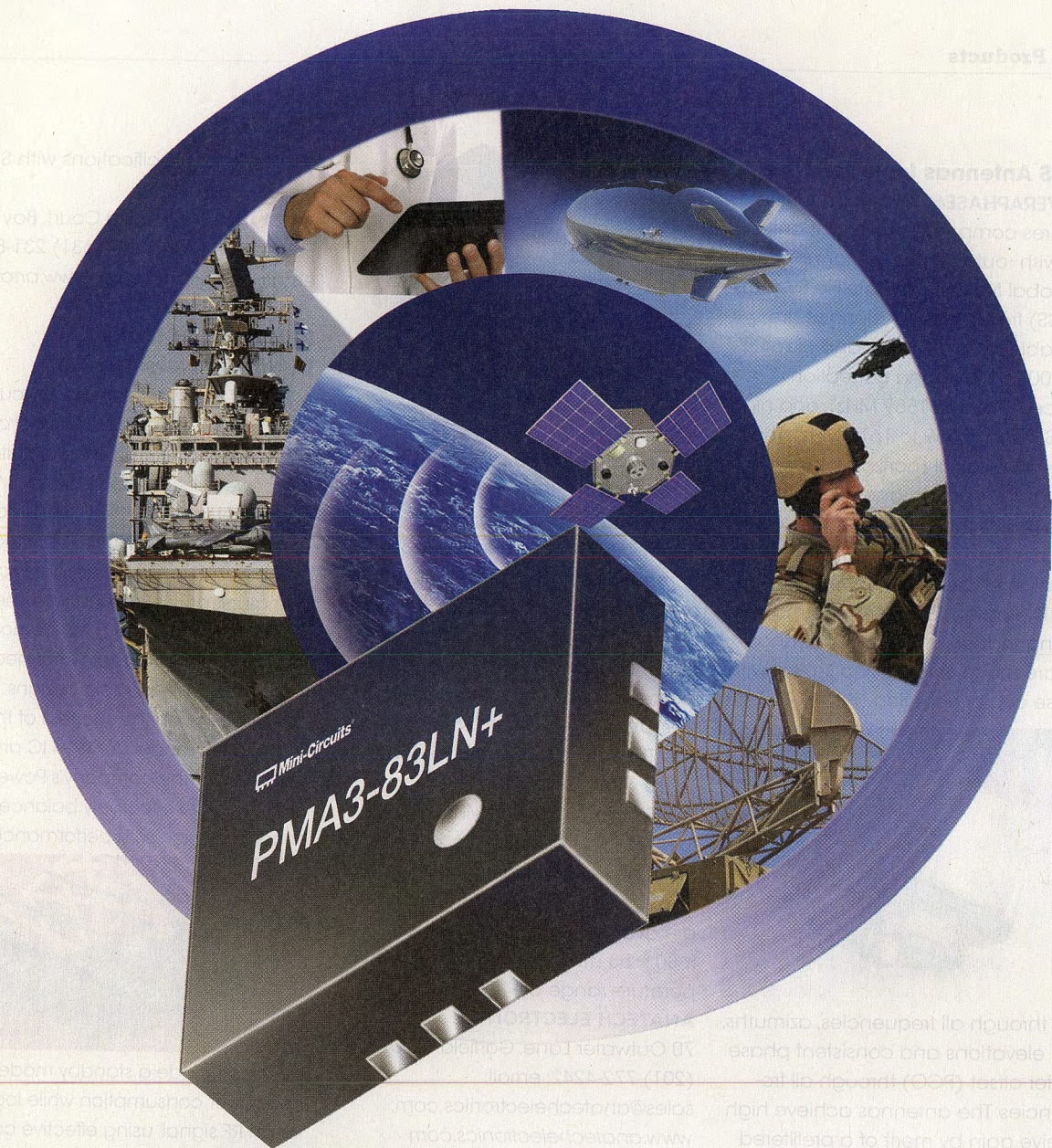
TRIAD RF SYSTEMS, 180 Tices Lane,
Building A, Suite 107, East Brunswick,
NJ 08816; (855) 558-1001; email:
sales@triadrf.com; www.triadrf.com

GaN Amplifier Powers X-Band

MODEL BME99109-40 is a solid-state power amplifier suitable for pulsed and continuous-wave (CW) applications at X-band from 9 to 10 GHz. It delivers 40 W (+46 dBm) output power using gallium-nitride (GaN) device technology, with nominal power gain of 46 dB. Suited as a replacement for traveling-wave-tube (TWT) amplifiers, the GaN amplifier features a 30-dB dynamic range over its 1000-MHz instantaneous bandwidth, with peak-to-peak phase stability of ± 2 deg. The Class AB linear amplifier operates with RF-to-DC efficiency of typically 18% or better and consumes 225 W maximum power from a supply of +36 to +45 VDC. The amplifier is screened for electrostatic-discharge (ESD) protection per IAW EN61000-4-2, MIL-STD-461F, and CS101/CE102 guidelines. It measures 4.00 x 4.00 x 3.33 in. and weighs 2.5 lbs.

COMTECH, 105 Baylis Rd., Melville, NY 11747;
(631) 777-8900; www.comtechpst.com





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*See datasheet for suggested application circuit.

†Flatness specified over 0.5 to 7GHz.

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FEATURES

- Low Noise Figure, 1.3 dB
- High Gain, 21 dB
- Excellent Gain Flatness, ± 0.7 dB†
- High IP3, +35 dBm
- High Pout, +23.2 dBm
- Tiny Size, 3x3 mm



GNSS Antennas Include LNAs

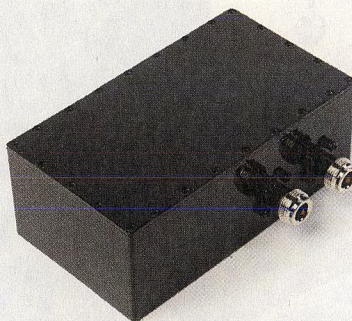
THE VERAPHASE6000 antenna series features compact, lightweight antennas with outstanding performance at Global Navigation Satellite Systems (GNSS) frequencies. Antennas are available for low GNSS band (1164 to 1300 MHz), L-band correction services (1525 to 1559 MHz), and high GNSS band (1559 to 1610 MHz). They provide low axial (horizon-to-horizon through all azimuth and elevations) ratios of less than 0.5 dB at the zenith and less than 2 dB at the horizon with high efficiency of better than 70%. The antennas offer performance rivaling that of choke-ring antennas but are much smaller and lighter, with phase center variation (PCV) of ± 1



mm through all frequencies, azimuths, and elevations and consistent phase center offset (PCO) through all frequencies. The antennas achieve high receive gain by merit of a prefiltered low-noise amplifier (LNA) with noise figure of better than 2.5 dB (non-filtered versions are available with noise figure of better than 1.5 dB). The antennas are also available with a printed circuit board (PCB) within the base of the antenna for use of mounting into different applications. These GNSS units are well suited for survey, precision real-time-kinematic (RTK), and reference antenna applications.

TALLYSMAN WIRELESS

106 Schneider Rd., Unit 3, Ottawa, Ontario, Canada K2K 1Y2; (613) 591-3131; email: sales@tallysman.com; www.tallysman.com



Filter Passes 910 to 920 MHz

MODEL AB915B656 is a rugged indoor/outdoor GSM-band cavity bandpass filter designed for both commercial and defense indoor and outdoor wireless applications. It combines high rejection, low return loss, and the capability to remove nearby interference. The filter has a passband of 910 to 920 MHz with 1.5-dB insertion loss. The return loss is greater than 16 dB with out-of-band rejection of 75 dB from 850 to 894 MHz and 929 to 950 MHz. It can handle 20 W CW input power and uses Type-N female connectors (others connector types are available). The filter measures 140 x 80 x 53 mm with an operating temperature range of -45 to +85°C.

ANATECH ELECTRONICS

70 Outwater Lane, Garfield, NJ 07026; (201) 772-4242; email: sales@anatechelectronics.com; www.anatechelectronics.com

Hybrid Links

500 to 1000 MHz

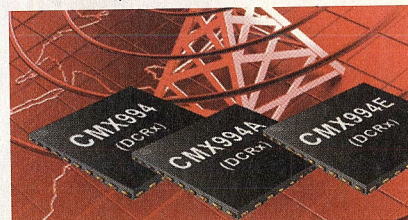
DESIGNED FOR broadband use from 500 to 1000 MHz, model 2164-90 is a 90-deg. hybrid coupler with better than 25-dB isolation between ports across the full frequency range. It operates with maximum VSWR of 1.25:1 and suffers maximum insertion loss of 0.25 dB while maintaining amplitude balance of ± 0.5 dB across the 500-MHz bandwidth. The rugged hybrid coupler handles 100 W average power and 5 kW peak power across the full frequency range. It is supplied in an aluminum housing per

MIL-C-39012 specifications with SMA female connectors.

ARRA, INC., 15 Harold Court, Bay Shore, NY 11706-2296; (631) 231-8400; email: sales@arra.com; www.arra.com

Receiver ICs Make Direct Conversions

A PAIR of receiver integrated circuits (ICs) developed by CML Microcircuits (www.cmlmicro.com) are well suited for low-power wireless applications. Models CMX994A and CMX994E are direct-conversion-receiver (DCRx) ICs that can be used for two-way radios and communications applications. They use in-phase/quadrature (I/Q) demodulators and work well in zero-intermediate-frequency (zero-IF) radio designs. The devices build on the success of the firm's earlier model CMX994 IC and make use of the company's PowerTrade technology to effectively balance power consumption with performance. The



devices include a standby mode for low power consumption while looking for an RF signal, using effective control of power cycling, phase control, and I/Q channel selection. The CMX994A delivers a very low power DCRx device while the CMX994E also includes the low power mode of the CMX994A but in addition, offers a high-performance mode with improved IP3 performance. The radio ICs feature on-chip voltage-controlled oscillator (VCO) for VHF applications, an on-chip low-noise amplifier, and baseband filters. Each IC runs on +3.0 to +3.6 VDC and is supplied in a Q4 40-pin VQFN package.

CML MICROCIRCUITS, 465 Corporate Square Dr., Winston-Salem, NC 27105; (336) 744-5050; email: us.sales@cmicro.com; www.cmlmicro.com

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- 50 W average models



4425 Types



9412 & 4401 Types
(1.14")



N9412 Types
(2.42")

Freq. Range (GHz)	Average Power (W)	Model No.	
		N Conn.	SMA Conn.
DC-18.0	1	N9412 *	9412 *
DC 5.0	1	N4402 *	4401 *
DC 4.0	5	N4405 *	4405 *
DC 4.0	10	N4410 *	4410 *
DC 4.0	25	N4425 *	4425 *
DC 4.0	50	N4450 *	4450 *

*Value of attenuation

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Freq. Range (GHz)	Average Power (W)	Model No.	
		N Conn.	SMA Conn.
DC-18.0	1	N9512	9512
DC-12.4	2	N9505	9505
DC-12.4	5	N9510	9510
DC-12.4	10	N9510	9510
DC- 8.0	25	N9525	9525
DC- 8.0	50	N9550	9550

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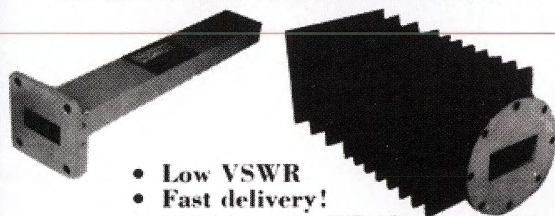
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2.60 3.95	1200	284 925	4500	284 920
3.30 4.90	1000	229 925	3000	229 920
3.95 5.85	750	187 925	2000	187 920
4.90 7.05	625	159 925	1500	159 920
5.85 8.20	500	137 925	1000	137 920
7.05 10.0	425	112 925	600	112 920
7.00 11.0	325	102 925	500	102 920
8.20 12.4	225	90 925	500	90 920
12.4 -18.0	200	62 925	250	62 920

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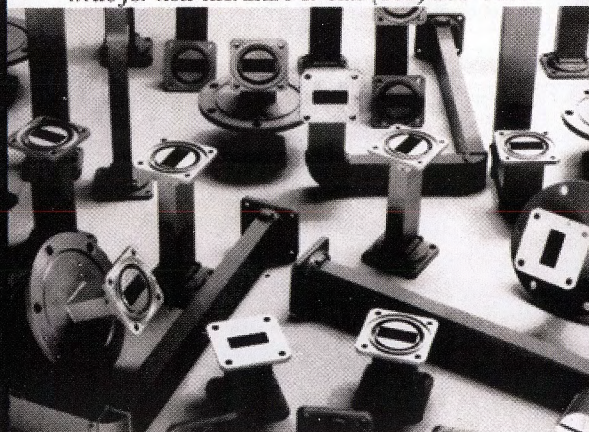
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